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Molecular phylogeny of south Indian *Aphthona* species (Coleoptera: Chrysomelidae: Galerucinae: Alticini) with evidence for colour polymorphism

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ABSTRACT: Phylogenetic relationships among south Indian *Aphthona* species using the cytochrome c oxidase subunit 1 mitochondrial gene (*COX1* or *COI*) is reported. This study confirms colour polymorphism in *Aphthona: A. tamila and A. glochidionae*; *A. marataka* and *A. macarangae,* respectively, could be confirmed as colour morphs. *Aphthona phyllanthae* is the most diverged taxon according to the genetic distance. © 2020 Association for Advancement of Entomology

KEY WORDS: Cytochrome oxidase, south Indian *Aphthona*, Molecular phylogeny

INTRODUCTION

The flea beetle genus *Aphthona* Chevrolat includes over 350 species distributed in the Old World (Konstantinov *et al.,* 2002). The species among this genus are ecologically diversified, occuring in a wide range of bio geographical areas from lowland rainforests to high-altitude coniferous hills and deserts to sub-arctic environments. This flea beetle genus is important in the biological control of invasive weed plants of the spurge family Euphorbiaceae (Roehrdanz *et al.,* 2009). Being monophagous, they are ideal candidates in biological control of these weeds. Most studies on *Aphthona* species have focused on morphological and behavioural data (Prathapan and Konstantinov 2003, 2011), only little molecular work has been published to date.

Only one species-level phylogeny of *Aphthona* has been published so far, that primarily considered the molecular phylogenetic analysis of five *Aphthona* species introduced to North America for biological control of leafy spurge (Roehrdanz *et al.,* 2011). Molecular systematics of Indian *Aphthona* spp. was never attempted. Hence, this study was carried out.

MATERIALS AND METHODS

A total of 25 specimens of adult *Aphthona* belonging to nine species (Fig. 2-10) were collected from different locations in south India among which, two specimens showing slight genital variation were designated as *A. chrozophorae* 1 and *A. chrozophorae* 2 (Table 1). Total genomic DNA was isolated from the collected specimens using DNA easy column method (Cockburn *et al.,* 1996;

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Reineke *et al.,*1998) using Qiagen, DNA easy; Blood and TissueKit as per the manufacturer's instruction. The DNA was quantified using spectrophotometric method (Gallagher *et al.,* 2006).

The cytochrome c oxidase subunit 1 mitochondrial gene (*COX1* or *COI*) was amplified using the forward primer with DNA sequence 5'-CATGGGG AATGCTTAGATGC-3' and reverse primer with DNA sequence 5'-AAACTTTCAGGGTGACC AAAAA-3'. The PCR reaction mixture consisted of 2 nanogram of genomic DNA (1 µl), 1 µl each forward and reverse primers at a concentration of 10 µM, 2.5 µl of dNTPs (2 mM), 2.5 µl 10X reaction buffer, 0.20 µl Taq polymerase (5 U/µl) and 16.8 µl H2O. The PCR profile consisted of an initial denaturation step of 5 min at 95°C, followed by 30 cycles of 10 sec at 95°C, 10 sec at 55°C and 1 min at 72°C and ending with a final phase at 72°C for 3 min. The PCR product was sequenced from both ends using the Sanger's sequencing (Sanger *et al.,* 1975) method at Rajiv Gandhi Centre for Biotechnology (RGCB), Trivandrum. The forward and reverse sequences were alligned using ClustalW (http://www.ebi.ac.uk/Tools/msa/clustalw2). After removing the forward and reverse primer sequences, the consensus sequence was taken for the analysis. The percentage of each nucleotide in the *COI* codon of *Aphthona* was determined by MEGA X software. A phylogenetic tree was constructed using MEGA software with ten sequences obtained, in order to understand the intrageneric genetic diversity among the species of southern Indian *Aphthona*. For this tree, *Chrysomela aeneicollis* was chosen as the outgroup.

RESULTS

A total of 25 *Aphthona* specimens were investigated in this study out of which, nine were distinct morpho-species (Table1; Fig. 2-10). All of the samples yielded good quality DNA having A_{260}/A_{280} ratio in the range of 1.8-2.0, which gave good amplicons in the PCR with a product size of 680bp. The phylogenetic tree illustrating relationships between the species of south Indian *Aphthona* species is provided (Fig.1). Using the Neighbour-Joining technique, evolutionary background was inferred. The optimal tree shows the distance of the branch being equivalent to 3.3. The evolutionary distances have been calculated using the technique Maximum Composite Likelihood and are in the number of base substitutions per unit. There were 11 nucleotide sequences in this study. The inclusion of codon positions was 1st+2nd+3rd+Noncoding. For each sequence couple, all unclear locations were deleted (pairwise deletion option). In the final dataset there were a total of 844 positions. The genetic distance between the species was

Table 1. Details of species collected

Sl. no	Species name	Host Plant	Location
1	*A. bombayensis*	*Phyllanthus amarus*	Vellayani, Kerala
2	*A. chrozophorae 1*	*Croton* sp.	Munnar, Kerala
3	*A. chrozophorae 2*	*Croton* sp.	Munnar, Kerala
4	*A. glochidionae*	*Glochidion zeylanicum*	Ponmudi, Kerala
5	*A. macarangae*	*Macaranga peltata*	Vellayani, Kerala
6	*A. mallotae*	*Mallotus philippinensis*	Dandeli, Karnataka
7	*A. marataka*	*Macaranga peltata*	Mattupettti, Kerala
8	*A. nigrilabris*	*Euphorbia hirta*	Vellayani, Kerala
9	*A. phyllanthae*	*Phyllanthus emblica*	Vellayani, Kerala
10	*A. tamila*	*Glochidion zeylanicum*	Pampadum Shola, Kerala

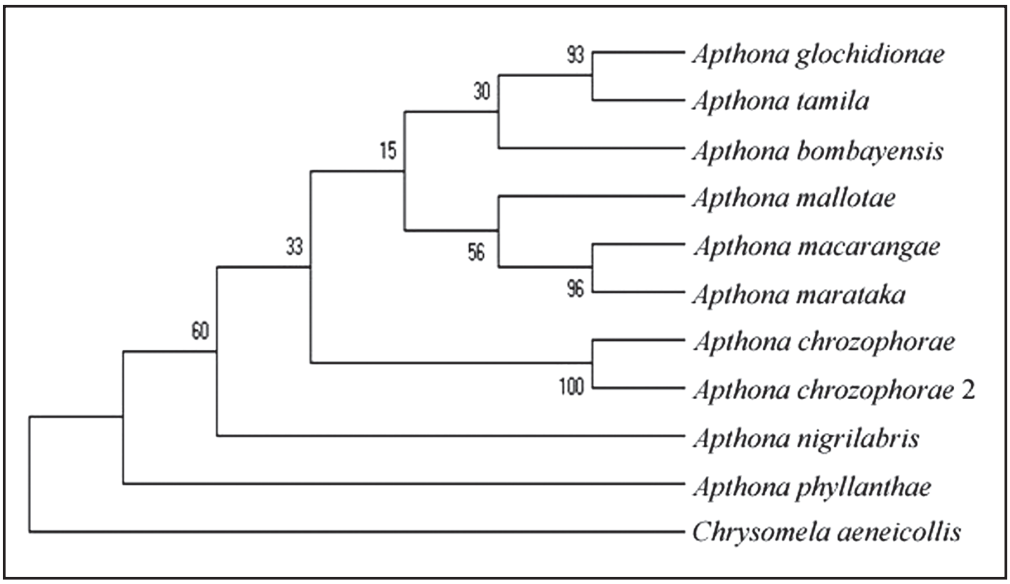


Fig. 1. Intragenomic phylogenetic tree of south Indian *Aphthona* spp.

calculated using MEGA (Tamura *et al.,* 2013) software by kimura 2 modelling (Kimura *et al.,* 1980) as depicted in table 2.

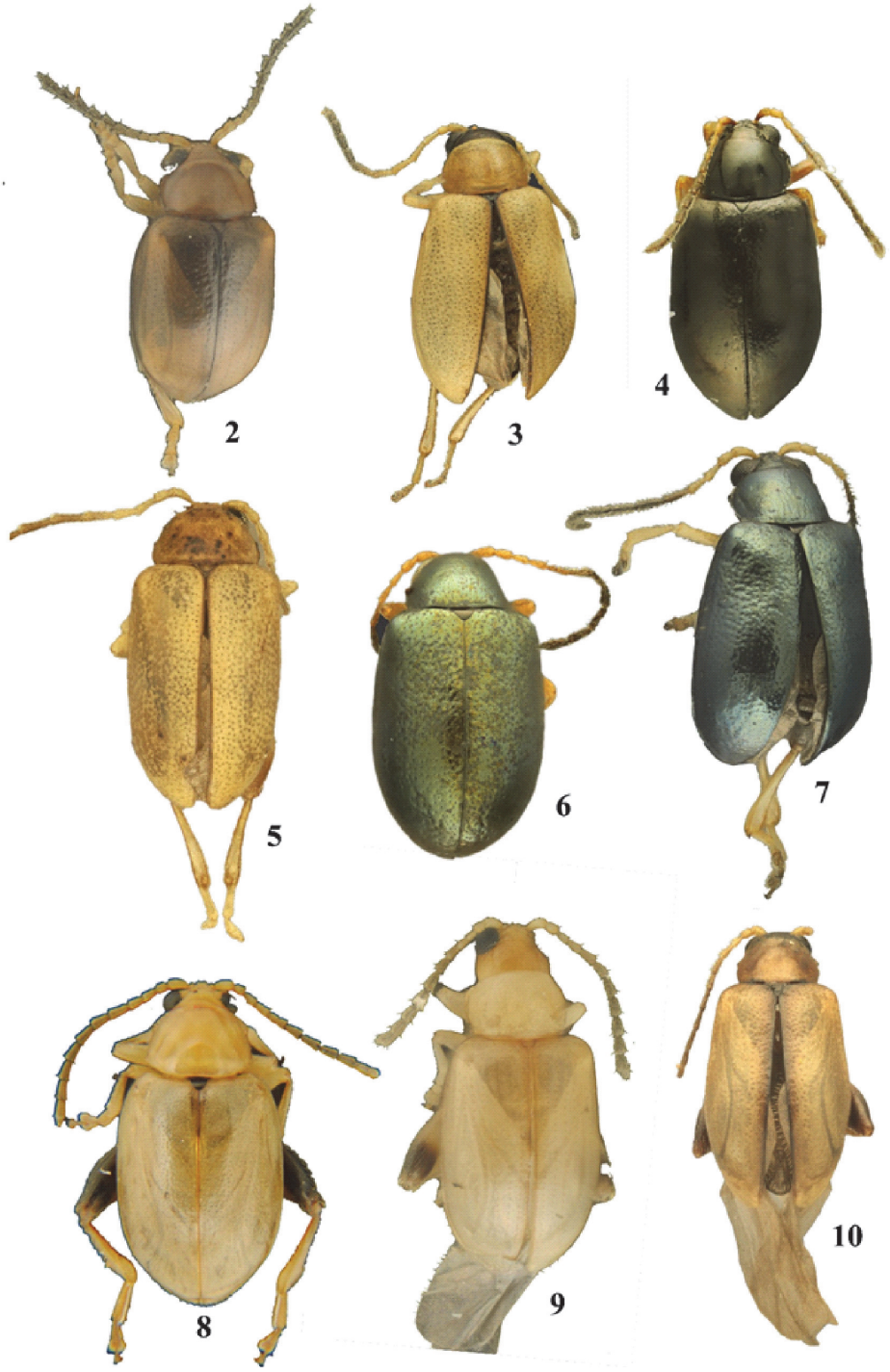
DISCUSSION

Based on prior cladistic research, *Aphthona* is defined by three synapomorphic characters: elytron length / width ratio below 2.85; anterior portion of the metanotal ridge connected below the centre of ridge b-1; and setae on the ventral side of the first sinuate metatarsomere (Konstantinov, 1998). *Aphthona* species are specialized phytophagous insects, as with most flea beetles. Most of them feed on crops from 11 distinct families (Nowierski *et al*., 2002).

From the genomic DNA, mitochondrial genes were amplified using selected primer. The amplification product was 700 bp in size; the same was used to generate sequences. The sequences were analyzed using BLAST (Altschul *et al.,* 1990). The genetic

Table 2. Genetic distance between south Indian *Aphthona* species.

Chrysomela_ aeneicollis										
A. bombayensis	0.295185									
A. chrozophorae_2	0.306005	0.22637								
A. chrozophorae_1	0.309262	0.226399	0.00341							
A. glochidionae	0.32423	0.20086	0.25555	0.25384						
A. mallotae	0.310312	0.211074	0.209836	0.214217	0.20297					
A. nigrilabris	0.279839	0.217638	0.195807	0.215064	0.196102	0.204721				
A. macarangae	0.320594	0.221219	0.197176	0.208616	0.195192	0.090091	0.21095			
A. phyllanthae	3.65206	3.6038	3.45497	3.45377	3.33880	2.84769	2.98418	3.0598		
A. tamila	0.267043	0.18270	0.23447	0.24313	0.13205	0.21412	0.21983	0.20680	3.21757	
A. marataka	0.32281	0.22121	0.19883	0.20861	0.19696	0.21317	0.21947	0.091659	3.0598	0.20836



Figs. 2-10. *Aphthona* spp. 2. *A. bombayensis;* 3. *A. chrozophorae;* 4. *A. glochidionae;* 5. *A. macarangae;* 6. *A. mallotae;* 7. *A. marataka*; 8. *A. nigrilabris;* 9. *A. phyllanthae;* 10. *A. tamila*

distance in the specified matrix ranges from 0.003 to 3.652. It is confirmed that, *A. phyllanthae* (Fig.9) is the most diverse species among the southern Indian *Aphthona*. The genetic distance between the species that created the same clade is as follows: the genetic distance between *A. glochidionae* and *A. tamila* is 0.132; genetic distance between *A. chrozophorae* and *A. chrozophorae 2* is 0.003 and distance between *A. marataka* and *A. macarangae* is 0.090. If genetic distance between two sequences is less than 0.2, then those species are considered as same (Vogle *et al.,* 1993). Hence, based on these observations of genetic distance, the aforesaid species can be considered as synonymous as they exhibit 99 percent sequence similarity. In *Aphthona*, the species group is determined by morphological characteristics, predominantly based on the morphological colour. The colours range from non-metallic yellow to metallic bright shades (Fig.2-10). There are no intermediate colouring patterns. Based on the genetic distance between the southern Indian *Aphthona* spp. calculated by kimura2 model, the species *A. marataka* (Fig.7) which is a bright metallic green coloured beetle, found in higher altitude habitats is identified to be synonymous with *A. macarangae* (Fig.5) which is yellow non-metallic in colour and inhabits lower altitude regions. The same applies to the metallic black species *A. glochidionae* (Fig.4) which inhabits high altitude areas, which is synonymous with the yellow non-metallic species, *A. tamila* (Fig.10) These species also share a significant quantity of resemblance morphologically. The presence of colour morphs within the *Aphthona* genus was not recognized until now. Similar kind of polymorphism in the subfamily Chrysomelinae of Chrysomelidae was reported by Van Noort, 2013. Thus, these species are recognized as colour morphs depending on morphological analysis and molecular information gathered from this study.

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Prevalence of *Stegomyia albopicta* (Skuse) (Diptera: Culicidae), in Dakshina Kannada district of Karnataka, India

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ABSTRACT: Dengue is one of the rapidly spreading mosquito-borne diseases transmitted worldwide by the bites of infected *Stegomyia aegypti* and *St. albopicta* mosquito. Both species are adapted for human habitation and breeds mainly in temporary water bodies. In the present study, a preliminary larval survey was carriedout in four different localities of Dakshina Kannada District. Of the 1094 suspected water bodies, 496 sites showed the presence of *St. albopicta* larvae and none of them showed the presence of *St. aegypti* indicating the dominance of the former species. The occurrence of *St. albopicta* was significantly higher in natural phytotelmata compared to artificial containers. Among the different breeding sites, receptacles contributed 24.5% of larval positivity. The receptacles also showed a higher breeding preference ratio (1.56) indicating that abandoned waste thrashes when receives water may act as the most preferred breeding sites for dengue vector species.
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KEYWORDS: Dengue, *Stegomyia mosquito*, habitats, receptacles

INTRODUCTION

Dengue is a widespread mosquito-borne disease prevalent throughout the tropics, with confined variations in risk influenced by unplanned urbanization. Globally approximately 3.9 billion people, in 128 countries are at the risk of infection with an estimated 390-500 million cases of dengue occurring every year (Brady *et al*., 2012; Gubler, 2012; Bhatt *et al*., 2013). *Stegomyia albopicta* (Skuse) (=*Aedes albopictus*), as a container breeding vector species of mosquito breeds both in natural and man-made water bodies. The species is considered as a reservoir vector of dengue especially in rural areas of dengue-endemic countries of South-east Asia and the Pacific islands (Tandon and Raychoudhury 1998). Globally, *St. aegypti* is considered as a primary vector and *St. albopicta* as a secondary vector of dengue fever (Sharma *et al*., 2014). The water storage system can provide easy breeding sites for these mosquitoes which may further enhance the disease transmission. Among the two dengue vectors, the *St. albopicta* out competes with *St. aegypti* because of its great adaptability and aggressive nature. In several parts of Kerala, *St. albopicta* carrying dengue virus, that too in the absence of *St. aegypti*, was reported (Tyagi, 2006). Studies also have shown that *St. albopicta* can play a significant role

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in the vertical transmission of dengue fever (Vazeille *et al*., 2003; Thenmozi *et al*., 2007).

The dengue virus (DENV) is an RNA virus with DENV1-4, four serologically and genetically distinguished serotypes. These four serotypes may involve multiple sequential infections which may further increase the magnitude of dengue epidemics (Shet and Kang, 2019). Dengue virus (DENV) infection of a human or mosquito host produces a dynamic population of closely related sequences. Such intra-host genetic diversity is thought to provide arboviruses an advantage for adapting as they pass between two very different host species (Sim *et al*., 2015). Over the past several decades, the dengue scourge march of mankind has expanded relentlessly, affecting more than 120 countries, putting more than four billion people at risk of dengue infection (Bhatt *et al*., 2013). In India, the earlier studies have shown that *St. aegypti* cause dengue transmission in cities and *St. albopicta* causes dengue transmission in suburban and rural areas (Delette *et al*., 2009).

The vector capacity of *St. albopicta* is well documented from different parts of Kerala carrying mainly dengue and chikungunya arboviruses (Thenmozhi *et al*., 2007; Regu *et al*., 2008; Sumodan, 2008). Change in the breeding pattern from the forest habitats to domestic ecotypes combined with aggressive diurnal human-biting behavior, ability to transmit a variety of viruses and occupation in the majority of temporary water bodies made this species not only dominant but highly dangerous especially in Southern India (Paulraj *et al*., 2016; Benedict *et al*., 2017). Widespread deforestation and increase in plantations especially rubber, cocoa and areca in forest-fringed hills contributed to the quick invasion of the *Stegomyia* species in Kerala and coastal districts of Karnataka. Due to the ecological adaptability, it entered into the rural and suburban niches, breeding extensively in rubber latex cup, receptacles, tanks, tires, shed leaf sheaths of areca palms, cocoa and other empty fruit pods (Hiriyan and Tyagi, 2004).

In Dakshina Kannada district, higher incidence of dengue has been reported in recent years (Fig. 1). Detection of larval habitats is essential for the identification of potential breeding grounds of the vector species and thus to recognize the source for the prevalence of the disease. Among the different components of dengue control, surveillance of vector species through larval and pupal collections is an important tool in disease epidemics and post-operational managements (Runge-Ranzinger *et al*., 2016). Since the semi-urban and rural areas of the different taluks are contributing the greater part of the dengue cases in the district, larval surveillance on the occurrence and breeding preference of the dengue vector has been carried out from the selected rural and semi-urban localities of the district.

MATERIALS AND METHODS

Larval Sampling: The monthly sampling was carried out from June 2016 to May 2017 in four localities of Dakshina Kannada district namely, Mudipu (12°48'10.06"N 74°57'50.98"E) (rural), Vitla (12°45'46.13"N 75° 6'5.15"E) (semi-urban) of Bantwal taluk and Kabaka (12°46'56.42"N 75° 9'41.54"E) (rural), Uppinangady (12°50'11.92"N 75°15'13.13"E) (semi-urban) of Puttur taluk respectively. In Dakshina Kannada, the average annual precipitation was 4,030 mm with the highest of 3037 mm of rain recorded during the monsoon season. The average humidity ranged from 62% to 89% and the mean temperature ranged from 20.8 to 34.0°C. Amongst a notable variety of microhabitats that retain water and supports aquatic stages of mosquito, 15 probable types were examined for the survey which were categorized as natural phytotelmata and artificial containers (Table 1).

The habitat preferences of *St. albopicta* for each type of positive breeding sites were assessed by calculating Breeding Preference Ratio (BPR) (Sharma, 2002) using the following formula:

$$\text{BPR (Y\%/X\%)} = \frac{\text{\% of positive breeding sites (Y \%)}}{\text{\% of the examined breeding sites (X \%)}}$$

$$\text{Where, X\%} = \frac{\text{No. of a particular type of breeding sites examined}}{\text{Total breeding sites examined}} \times 100$$

$$\text{Y\%} = \frac{\text{No. of a particular type of breeding sites positive for } \textit{St. albopicta}}{\text{Total positive breeding sites examined}} \times 100$$

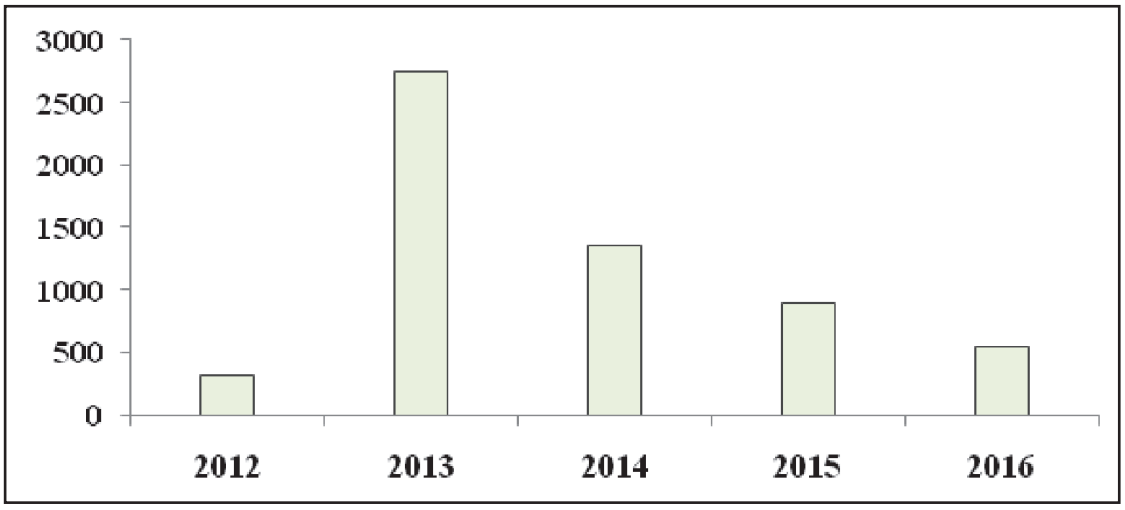

Fig. 1. Number of dengue incidences in Dakshina Kannada district (District Health Office Report)

Table 1. Classification of *St. albopicta* breeding sites surveyed in Dakshina Kannada district.

Sl.No	Natural containers of phytotelmata origin	Sl.No	Artificial containers
1.	Leaf axils	1.	Receptacles#
2.	Tree-holes	2.	Tires
3.	Bamboo stump	3.	Cement cistern with vegetation
4.	Fallen leaf	4.	Cement Water storage tanks
5.	Areca sheath	5.	Plastic water storage containers
6.	Coconut husks or shells	6.	Cesspits
7.	Cacao pods	7.	Latex cup
8.	Tree logs		

#discarded solid waste such as bottles, cans, plastic and metal containers, etc.

The differences in the occurrence of *Stegomyia* larvae between artificial and natural sites were statistically analyzed using the Chi-square test. Further, for artificial containers sampled from the residential area, container index (CI) was also calculated as per the WHO guidelines (2003).

In each locality, approximately 500m^2 area covering residential and areca plantation areas were surveyed to detect *Stegomyia* larval breeding. In residential sampling sites, water bodies in and around the cowsheds, dairy farms, poultry farms were also surveyed as these places provide plenty of hosts for blood-feeding which may influence the oviposition of the mosquito. The larval collections were made using dipping and pipetting methods. Only those water samples which showed the occurrence of *Stegomyia* larvae and pupae were transferred to a plastic bottle marked with a label and then taken to Zoology laboratory, Vivekananda College, Puttur for further processing. The identification of species was mainly based on the morphological characters of both larvae and adult specimens using a standard key (Barraud, 1934). Further, the confirmation of species was done by the hypopygium mounting of the adult male (Huang, 1979). The latest abbreviations of generic names provided by Reinert (2009) were used in the study.

RESULTS AND DISCUSSION

Of the 15 different types of water bodies surveyed, *St. albopicta* was documented from 14 types of breeding sites except cesspits (figure 2). From a total of 1,064 water-holding sites surveyed, constituiting 49.2% phytotelmata and 50.8% artificial containers surveyed 494 sites with 46.42% had *St. albopicta* larvae. Of the preferred habitats, receptacles contributed highest of 24.49% (n=121) followed by areca sheath with 20.64% (n =102) and tyres with 10.52% (n=52). Studies have shown that *Stegomyia* mosquito thrives well in discarded and unused receptacles and water collected in the plant materials especially during the rainy season (Samuel *et al*., 2014). *St. albopicta* was abundantly collected from peridomestic containers and water bodies associated with plantations from the hilly regions and rural areas of Kerala state (Eapen *et al*., 2010).

The number of breeding sites varied in different seasons. In monsoon, 300/557 (53.8%) sites including 145 phytotelmata and 155 artificial containers showed larval presence. In post-monsoon, 149/313 (47.6%) sites including 85 phytotelmata and 64 artificial containers showed the presence of dengue larvae. However, in the pre-monsoon period, only 45/194 (23.19%) showed the larval existence. *St. albopicta* was more dependent on rainfall and its larval density sharply increased with the onset of monsoon rains which filled up the peridomestic containers and phytotelmata spread in the area. During monsoon season, areca plantations with abandoned receptacles, area sheath and other plant materials such as leaves, pods have been found to be excellent breeding sites for the proliferation of the vector species. Human dwellings and grazing cattle in the surrounding area of the plantations provides easy blood meal. Dengue vectors were reported during both pre-and post-monsoon seasons at higher altitudes of Western Ghats (Ravikumar *et al*., 2013).

Among the water bodies, the occurrence of *St. albopicta* larvae was found to be 42.54% and 51.26% in artificial containers and natural phytotelmata respectively. The prevalence of *St. albopicta* showed a significant difference in natural and artificial habitats (÷2=8.01, P<0.05). The *St. albopicta* has greater adaptability to breed in domestic as well as natural water bodies. Being originally a forest species, it rapidly adapted to human habitation as a container breeder due to widespread deforestation and conversion of forest into agricultural settlements. Due to the rapid invasiveness, it spread to rural and suburban niches

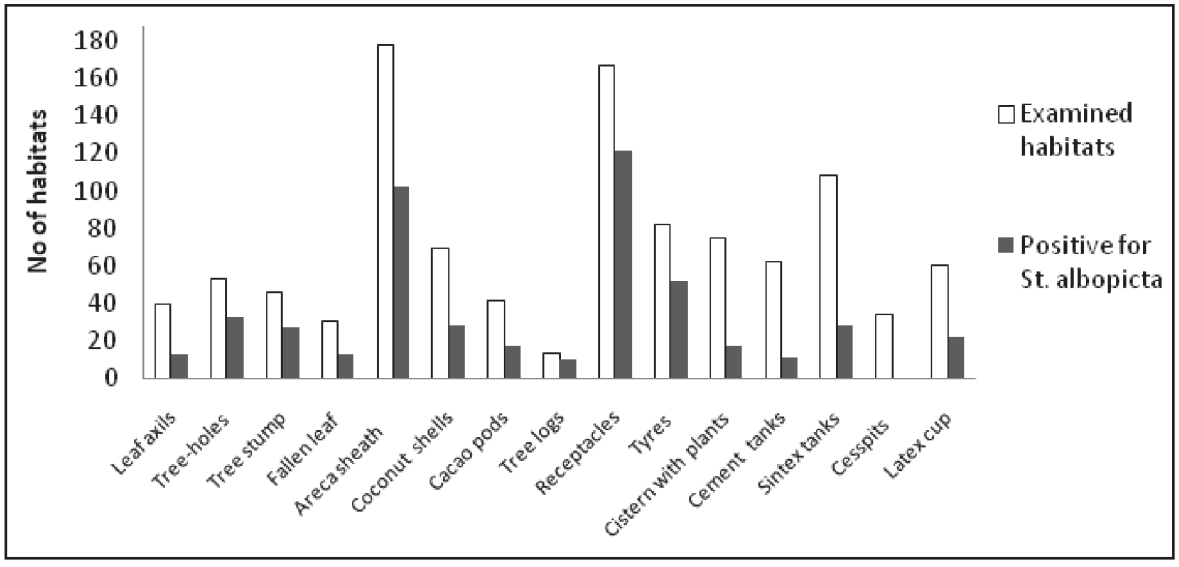

Fig. 2. Breeding sites surveyed for the occurence of *St. albopicta*

Table 2. Breeding preference ratio (BPR) of *St. albopicta* in different breeding sites of Dakshina Kannada district

Types of breeding habitats		No. of breeding sites		% X	% Y	BPR (%Y / %X)
		Examined (X)	Positive for *St. albopicta* (Y)			
1	Leaf axils	40	13	3.75	2.63	0.7
2	Tree-holes	53	33	4.98	6.68	1.34
3	Tree stump	46	27	4.32	5.46	1.26
4	Fallen leaf	31	13	2.91	2.63	0.9
5	Areca sheath	178	102	16.72	20.64	1.23
6	Coconut shells	70	28	6.57	5.66	0.86
7	Cacao pods	42	17	3.94	3.44	0.87
8	Tree logs	14	10	1.31	2.00	1.54
9	Receptacles	167	121	15.69	24.49	1.56
10	Tires	82	52	7.7	10.52	1.36
11	Cistern with plants	75	17	7.04	3.44	0.48
12	Cement tanks	62	11	5.82	2.22	0.88
13	Sintex tanks	109	28	10.24	5.66	0.55
14	Cesspits	34	0	3.19	0	0
15	Latex cup	61	22	5.73	4.45	0.77
	Total	1064	494			

breeding in artificial containers like plastics and tyres. The concomitant destruction of natural habitats forced the species to breed in domestic containers besides natural sites (Almeida *et al*., 2005). In the neighboring state of Kerala, the larval occurrence was reported from several phytotelmata bodies such as areca sheaths, coconut pods, tree holes, leaf axils (Rao, 2010). The acclimatization of *St. albopicta* to breed in water collected in phytotelmata bodies was found to be a serious concern, as these structures provide stable oviposition sites for the prevalence of mosquito species even in the dry seasons (Eapen *et al*., 2010).

The Breeding Preference Ratio (BPR) has also been computed for the *St. albopicta* recorded in the study area (Table 2). Receptacles (1.56) i.e. discarded containers were found to be the most preferred breeding sites followed by logged trees (1.54), tyres (1.36) and tree holes (1.34). Water in these containers is stored for longer durations mainly because of rainfall, making them as productive breeding grounds. The earlier studies have indicated that the discarded utensils have higher BPR compared to that of the containers used for water storage (Singh *et al.*, 2008, 2011). Tyres are particularly useful oviposition sites, as they are often stored outdoors and collect and retain rainwater effectively for a long time. Along with these, the addition of decaying leaves and other organic matters produces similar environmental conditions to tree holes, which provide an excellent substratum for breeding (Kweka *et al.,* 2018). The earlier studies have shown that *St. albopicta* may use natural phytotelmata to breed and thrive in non-urbanized areas, increasing more public health concerns in rural areas. Careless dumping of waste plastic, thermacol and metallic containers in and around the houses may cause a major problem,

especially in monsoon season, as these eventually become the breeding ground for the mosquito larvae. The BPR is low (0.48) for cistern with plants indicating the lesser preference of *Stegomyia* larvae to permanent water bodies. The container index was maximum in monsoon (56.77) followed by post-monsoon (39.75) and pre-monsoon (20.51).

The *St. albopicta* was found to co-exist with 10 species of mosquitoes namely *Anopheles stephensi, Armigeres subalbatus, Ar. aureolineatus, Fredwardsius vittatus, Culex quinquefasciatus, Cx. tritaeniorhynchus, Cx. gelidus, Cx. nigropunctatus, Cx. mammilifer* and *Toxorhynchites splendens* in different breeding sites. In recent years, studies have documented the co-occurrence of Stegomyia larvae with some species of Anopheline and Culicine larvae (Chen *et al*., 2006; Wan-Norafikah *et al*., 2009; Rohani *et al*., 2010). The coexistence of *St. albopicta* with *St. aegypti, Ar. subalbatus* and *Cx. quinquefasciatus* in tree holes and in trashed water bottles indicate that vector species in different breeding sites can share the habitats (Hawley, 1988; Sultana *et al*., 2017). But this co-occurrence of multiple species dependent on the habitat types, mosquito species and other physicochemical parameters of the water bodies.

From the present larval surveillance, it can be concluded that *St. albopicta* is a well-established species in the district especially in rural areas with the highest occurrence during monsoon season. The higher occurrence of larvae in phytotelmata associated with plantations may be one of the main reasons for the higher incidences of dengue fever in rural areas. Interestingly, in none of the habitats, the existence of *St. aegypti* has been reported indicating the dominance of species *St. albopicta* and the role of *St. albopicta* as the vector of dengue and chikungunya (Paulraj *et al.,* 2016). A similar survey carried out in the Lakshadweep islands, revealed the predominance of *St. albopicta* and the absence of *St. aegypti*. Early studies indicate that the decline and virtual disappearance of *St. aegypti* in rural and suburban areas by *St. albopicta* is due to the competitive displacement which occurs mainly due to the breeding preference of former species in natural habitats (Black *et al*., 1989). Climate change is one of the key factors responsible for the rapid expansion of *St. albopicta* (Roiz *et al*., 2011; Proestos *et al*., 2015). *St. albopicta* found to be one of the most aggressive outdoor species, and their day-biting behaviour aided by very broad host range including humans, domestic animals, amphibians, reptiles, and birds makes the species an important susceptive vector for dengue fever (Eritja *et al*., 2005). So it is very much obligatory to tackle this mosquito species before it takes the district to yet another dengue disease epidemic condition.

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Population ecology and ETs based time series for climate smart pest management of *Spilosoma obliqua* (Walker)

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ABSTRACT: The two-sex pooled life table of *S. obliqua* (Walker) (Lepidoptera: Arctiidae) was constructed along with their population density and yield loss estimation to determine their economic thresholds (ETs) based time series on two different crops such as sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54) in 2019. The population ecology and ETs of *S. obliqua* were significantly (P<0.05) affected by the host phytoconstituents in terms of host suitability or susceptibility (sesame>green gram). Average EIL and ET for *S obliqua* was 26.388±1.627 and 24.230±2.412 pests/30 plants, respectively for sesame that were insignificantly ($F_{1,4}$=2.794-3.335; P≥0.142) differed from the green gram. For a single pest per m^2 (30±2 plants/m^2) the possible time that can be taken to reach EIL (Ti) and ET (Tt) were 38.246±1.157 and 37.246±1.157 days, respectively on sesame which were significantly ($F_{1,4}$=24.111; P=0.008) lower than green gram. Even, ETs based time series was also calculated to find the specific time (Tt days) to reach ET for any number of pest(s)on the selected crops for time based management. The benefit cost ratio (BCR/ha) of sesame and green gram was 0.478 and 0.390, respectively with significant (P<0.05) deviation. The carbon sequestration efficiency (CSE) of sesame (301.860 kg/ha) was significantly (P<0.05) higher than green gram (172.260 kg/ha) due to more biomass production. These findings will obviously help farmers to choose sesame as a suitable trap crop for green gram on the basis of pest attraction or susceptibility, ETs based time series, BCR values (sesame>green gram) as well as CSE for climate smart pest management (CSPM) by applying appropriate control measures judiciously if required within the time limit to reach the ETs as in time series for sustainable climate smart agriculture (CSA) of such crops in near future.
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KEY WORDS: *Spilosoma obliqua*, *Sesamum indicum*, *Vigna radiata*, phytoconstituents, population ecology, ET, trap crop, carbon sequestration efficiency, climate smart pest management.

INTRODUCTION

Sesame (*Sesamum indicum* L., Family: Pedaliaceae) is the most important oilseed crop in tropical and subtropical regions of the world (Chongdar *et al*., 2015), while green gram (*Vigna radiata*, Family: Fabaceae) is an important short-season summer growing legumes and is also grown widely throughout tropic and sub tropic regions (Roy and Barik, 2010; Mobarak *et al*., 2019). In West Bengal, several cultivars of sesame (Rama, Savitri, Tillotama, Nirmala, Shubhra, Amrit, JLT-408, TKG-22, DSS-9, GT-2, etc.) and green gram (K-851, PDM-54, B-105, Pusa Baishakhi, Sonali, etc.)

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are cultivated (Chongdar *et al*., 2015; Mobarak *et al*., 2019). However, their productivity is extremely low due to several yield limiting factors like biotic and abiotic stresses with poor agronomic management practices (Adhikary *et al*., 2018). Among the insect pests, Bihar hairy caterpillar of *Spilosoma obliqua* (Walker) (Syn. *Diacrisia obliqua*) (Lepidoptera: Arctiidae) is one of the major generalist pests of different crops including sesame and green gram in India, Bangladesh, Bhutan, Srilanka, Pakistan and south-eastern Afghanistan (Nath, 1975; Mobarak *et al*., 2019). All the larval instars (I-VI) feed voraciously on their host leaves as well as pods and ultimately reduce crop productivity (Bhaduria *et al.,* 2001; Biswas, 2006; Roy and Barik, 2013; Mobarak *et al*., 2019). Today, the use of different high yielding varieties (Wolfenberg and Phifer, 2000; Mobarak *et al*., 2019), broad-spectrum synthetic pesticides like, triazophos, lambda cyahlothrin, indoxacarb, cypermethrin, deltamethrin**,** etc. (Nagia *et al.,* 1990; Mohapatra and Gupta, 2018), botanicals (Parui and Roy, 2016, Bhardwaj and Kumari, 2016), natural enemies (Damalas and Koutroubas, 2018), etc. are used for effective management of *S. obliqua*. But all the strategies are so far unable to manage the pest completely. So, farmers use more pesticides injudiciously for even a single pest observation without considering any economic threshold (ET) limit or irrespective of pest density to eradicate the pest population completely for better crop production (Nagia *et al.*, 1990; Jashvantbhai, 2015; Carvalho 2017; Mohapatra and Gupta, 2018). These create ecological imbalance in the agroecosystem and result into secondary pest outbreak, pest resurgence, development of pesticide resistance as well as emergence of pest biotypes (Kim *et al*., 2017).

To stop such creation of more ecological imbalance, pest population ecology based management strategy is necessary to combat with the pest (Chi and Su, 2006; Chen *et al.*, 2017; Roy and Barik, 2012; 2013; Roy, 2015a; 2015b; 2019; Mobarak *et al.*, 2019). Population dynamics and nutritional ecology based ET calculation for sustainable management of a pest are very crucial (Southwood 1978; Carey 1993; Dutta and Roy 2016; Chen *et al.*, 2017; Roy, 2015a, 2015b, 2017, 2019). Life table is a powerful tool to understanding the effect of different hosts on an insect pest as well as their management (Southwood, 1978; Carey, 2001; Kakde *et al*., 2014; Roy, 2019). The age-stage, two-sex life table is more powerful than traditional life table as it can eliminate many inherent errors due to sexual biasness (Chi and Su, 2006; Chen *et al*., 2017). There is a range of innet capacity for individual of a population (Roy, 2015b; Dutta and Roy, 2016) but the variation in available host plant quality always influence the growth, reproduction, longevity and survival of that population (Liu *et al*., 2004; Schoonhoven *et al*., 2005; Shobana *et al*., 2010; Win *et al*., 2011; Roy and Barik, 2012, 2013; Roy, 2019). Different host plants vary in the context of various physical and chemical characteristics (Schoonhoven *et al*., 2005; Shobana *et al*., 2010; Roy and Barik, 2012). Host phytoconstituents mediated defences against the herbivores are wide-ranging and highly dynamic in nature (Awmack and Leather, 2002; War *et al*., 2012). Secondary metabolites (polyphenols, terpenoids, alkaloids, etc.) either produced constitutively or in response to plant damage, and they affect feeding, growth, and survival of herbivores (Howe and Jander, 2008; War *et al.,* 2012). Moreover, host plant utilization is also influenced by the ability of insect to ingest, assimilate and convert food into their body tissues (Scriber and Slansky, 1981; Dadd, 1985; Nation, 2001). Thus, host plant quality during larval growth and development is the key determinant of adult longevity, fecundity, fertility and survivability (Awmack and Leather, 2002; Shobana *et al*., 2010; Roy and Barik, 2013; Roy, 2015a). The effect of different food sources on population parameters were observed in *Plutella xylostella* (Syed and Abro, 2003), *Helicoverpa armigera* (Liu *et al*., 2004), *Spodoptera litura* (Xue *et al*.,2010), *Papilio polytes* (Shobana *et al.,* 2010), *Diacrisia casignetum* (Roy and Barik, 2013), *Podontia quatuordecimpunctata* (Roy, 2015a), *Epilachna vigintioctopunctata* (Roy, 2017) and *Parallelia algira* (Munrswari *et al*., 2019) on different host plants. Variation between the results of this studies could be attributed to differences among nutritional and anti-nutritional factors present in the respective

host plants (Awmack and Leather, 2002; Xue *et al*., 2010; Roy and Barik, 2013). Similarly, a number of biological studies have been reported for *S. obliqua* on sunflower (Varatharajan *et al.,* 1998), sesame (Biswas, 2006), jute (Gotyal *et al*., 2015), black gram (Mandal *et al*., 2013) and green gram (Mobarak *et al*., 2019). Even, there are few reports on carbon sequestration efficiencies (CSE) of different crops for climate smart agriculture (CSA) to mitigate the climate change (Albrecht and Kandji, 2003; Wang *et al*., 2016; Chhetri *et al*., 2017; Aryal *et al*., 2018; Anuga *et al*., 2019; Subedi *et al*., 2019). But, till date none of the studies has been performed with *S. obliqua* on sesame and green gram in a comparative manner by using population dynamics and nutritional ecology based ETs determination for their any sustainable management. Thus, my objectives of the present study were to (i) determine the host preference based on nutritional ecology and population dynamics of *S. obliqua* for ETs calculation, (ii) understand the pest density from the field and economic attributes beyond the field along with their population growth parameters on the selected crops to find the appropriate ETs of *S. obliqua* for time series calculation to apply any suitable control measures within the time limit (iii) and also determine the Carbon Sequestration Efficiency (CSE) of the selected crops to mitigate the climate change by climate smart pest management (CSPM) of *S. obliqua*as a part of CSA.

MATERIALS AND METHODS

Host plants: Two economic crops i.e., sesame (*S. indicum*; Pedaliaceae; cv. Rama) (Chongdar *et al*., 2015) and green gram (*V. radiata*; Fabaceae; cv. KB-54) (Roy and Barik, 2010) were cultivated and collected from a selected field situated near Chinsurah Rice Research Center (CRRC), Chinsurah, 22°53' N, 88°23' E, 13m above sea level, Hooghly, West Bengal, India, during summer season (February to June) in 2019. The plants were also identified and voucher specimens (Voucher No. ERU 23-24) were kept in Department of Zoology, Ecology Research Unit, M.U.C. Women's College, Burdwan, West Bengal, India. The selected crops (sesame and green gram) were separately germinated on moistened filter papers and each crop was grown in three side by side plots [plot size 10 m× 10 m; gap 0.5 m between two plots; soil organic matter 5.3 ± 0.2%, pH 7.7, photoperiod 13 L: 11 D at 30–35°C].All the plots were maintained without any insecticide for natural infestation of *S. obliqua* (Fig. 1 A & B). Intact mature leaves of 4-5 week old plants were collected separately from the respective crops for phytochemical analysis as well as for food of *S. obliqua* neonates for their population study.

Phytochemical analysis: The intact mature leaves of the crops were initially rinsed with distilled water and dried by paper towelling separately for phytochemical analysis. They were extracted in different solvents for extraction of different primary and secondary metabolites. The phytochemicals such as total carbohydrates, proteins, lipids, amino acids, phenols, flavonoids, tannins, saponin, alkaloid, phytate, oxalate, nitrogen and moisture content were estimated by various standard biochemical analysis protocols (Harborne, 1973; 1994) as in Roy (2015a; 2015b; 2017; 2019). Total alkanes, free fatty acids as well as free and bound amino acid content were also determined as in Roy (2018; 2019). Determination of each biochemical analysis was repeated for three times during 2019 and was expressed in dry or fresh weight basis accordingly.

Insect mass culture: The initial populations of *S obliqua* larvae were collected from each crop (sesame and green gram) separately from the cultivated fields in 2019. The larvae were incubated separately in the laboratory condition at 26±1°C, 60±5% RH and a photoperiodism of 12:12 (L:D) on intact mature leaves of the selected crops in glass jars (20 cm dia. × 30 cm ht.) until their pupation. After emergence of adults from the reared pupae six pairs of newly emerged male and female were placed in a glass jar (20 cm dia. × 30 cm ht.) containing the same mature leaves of each crop for their oviposition in an oviposition cage of fine nylon net (25×25×25 cm) containing a small cotton ball soaked with 10% honey solution for adults' feeding to obtain same aged eggs of *S obliqua* as described previously (Roy and Barik, 2013; 2014; Roy 2015a; 2015b; 2017). On each crop cultivar,

newly laid eggs by the F_3 females were collected in order to obtain the same aged eggs of defined cohort (n=100) on each crop cultivar for stock culture of *S obliqua* up to three generations. The population data (developmental duration and survival) throughout their life cycle were recorded separately by using fourth generation (F_4) data (cohort size: n=100) on the selected crop cultivars with three replications in 2019 at same conditions [ten eggs in a glass jar (20 cm dia. × 30 cm ht.)] in a growth chamber as described previously (Chi and Su, 2006; Roy 2015a; 2015b; 2017; 2019).

Feeding dynamics: Feeding ecology was conducted by taking the F_4 newly emerged larvae that had been reared in the same laboratory condition on the selected crop cultivars separately as in previous experiments (Roy 2015a; 2015b; 2017; 2019). Larvae were weighed initially and were placed in a glass jar (20 cm dia. × 30 cm ht.) containing leaves of a particular crop cultivar. The larvae were allowed to feed on the pre-weighed leaves from each cultivar for 24 h interval, and remaining leaves after 24 h of feeding were reweighed. Sample leaves from each crop cultivar initially and after 24 h were weighed, oven dried and reweighed to determine dry weight conversion factor (DWCF) for estimation of diet dry weight supplied to the larvae. Similarly leaf dry weight conversion factor (LDWCF) for the different instars and their faeces were also determined for estimation of the dry weight gain of the larvae after feeding. Food utilization indices were calculated by the formulae of Waldbauer (1968) with essential modifications as described elsewhere (Roy and Barik, 2013; Roy, 2015a, 2015b; 2017). All the feeding indices like, growth rate (GR), consumption rate (CR), relative growth rate (RGR), consumption index (CI), egestion rate (ER), host consumption rate (HCR), approximate digestibility (AD%), efficiency of conversion of ingested food (ECI%), efficiency of conversion of digested food (ECD%) and host utilization efficiency (HUE%) including feeding index (FI), growth index (GI) and pest susceptibility index (PSI) were estimated as in Roy (2015a; 2015b; 2017).

Life table study: The data on survival, developmental duration and oviposition of all individuals on the selected crops (sesame and green gram) cultivar were analysed separately based on age-stage and two-sex life table theory (Chi and Su, 2006; Chen *et al*., 2017; Roy, 2019). With the formulae of Southwood (1978), Carey (1993), Krebs (1994), Price (1998) and Kakde *et al*. (2014) to arrive the probability of survival from birth to age x (l_x), proportion dying each age (d_x), mortality (q_x), survival rate (s_x) per day per age class from egg to adult stages. Using these parameters, the following statistics like total individuals at age x and beyond k (T_x), average population alive in each stage (L_x), life expectancy (e_x), exponential mortality or killing power (k_x), total generation mortality (K or GM), generation survival (GS), gross reproductive rate (GRR), net reproductive rate (NRR or R_0), mean generation time (T_c), doubling time (DT), intrinsic rate of population increase (r_m), Euler's corrected r (r_c), finite rate of population increase (λ), weekly multiplication rate (λ^7), increase rate per generation (λ^{Tc}), were also computed, using Carey's formulae (1993). Some other population parameters like potential fecundity (Pf), total fertility rate (F_x), mortality coefficient (MC), population growth rate (PGR), population momentum factor of increase (PMF), expected population size in 2^{nd} generation (PF_2), Hypothetical females in 2^{nd} generation (HFF_2), expected females in 2^{nd} generation (FF_2), general fertility rate (GFR), crude birth rate (CBR), reproductive value (RV), vital index (VI) and trend index (TI) were also determined by using well defined formulae (Southwood, 1978; Carey, 1993; Roy, 2019).

Field experiment: A field experiment was conducted in 2019 by growing selected crops (sesame and green gram) cultivar in randomized block design (RBD) to determine the economic threshold (ET) of BHCs of *S obliqua* as described by earlier workers with few modifications (Parui and Roy 2016, Roy, 2019). The experiment was carried out in 10 katha or 670 m^2 near CRRC, Chinsurah, 22°53' N, 88°23' E, 13m above sea level, West Bengal, India, with three replications for both control and treated plots (10 m× 10 m) as described above with average plant density of 30±2 plants/ m^2 (Parui and Roy, 2016). The data from the

selected crops were collected for determination of ETs of *S obliqua* for the crops. The yield potential of the selected crops was observed over a traditional synthetic pesticide, Triazophos 40 EC (@ 40g a.i/ha) along with control (without pesticide) side-by-side (Parui and Roy, 2016; Mohapatra and Gupta, 2018).

Yield loss and ET calculation: From seed sowing to harvest of the selected crops (sesame and green gram) cultivar, the occurrences of BHC(s) of *S obliqua* were recorded by random quadrat sampling (RQS) from each treated and control plots (Parui and Roy, 2016). Calculation of economic injury level (EIL) for *S. obliqua* according to the methodology proposed by Pedigo *et al*. (1986) expressed as numbers or injury equivalents and governed by four primary variables viz. cost of the management tactic per production unit (*C*), market value per production unit (V), D' = percent yield loss per pest and the proportional reduction in pest attack (*K*). If the relationship of these variables is linear or roughly so, the EIL can be given as EIL = C/VD'K (Pedigo *et al*., 1986; Pedigo and Buntin, 1994). The economic threshold (ET) is the population density at which control action should be determined (initiated) to prevent an increasing pest population (injury) from reaching the EIL (Pedigo and Higley,1992). The cost of control (C) includes cost of the insecticide plus application, although others could be added (Higley and Wintersteen 1992; Pedigo and Higley 1992). On the basis of BHC infestation and the efficacy of the traditional synthetic pesticide were determined in terms of yield damage reduction (%), proportion of insect controlled (%) and per cent yield loss per pest per plant (%) along with the management costs (CC) for the calculation of EIL, ET, time to reach the EIL and ET when a plant was infested by a single pest in the field (Roy, 2019). The management cost was calculated using the cost of the insecticide, Triazophos 40 EC (Mohapatra and Gupta, 2018). A time series was also calculated up to reach the ETL from population growth data. The benefit cost ratio (BCR) was also determined (Chongdar *et al*., 2015) to find the seed production efficiency as well as resistance of the selected crop (sesame and green gram) cultivars over BHC (s) of *S obliqua* as the sole pest infestation.

Determination of Carbon sequestration: The transfer of carbon (C) by sequestering carbon dioxide (CO_2) in the green biomass and its sink into the soils organic carbon (SOC) is one of the most important strategies to address the carbon sequestration efficiency (CSE) of any plant to mitigate climate change by reduced GHG emission (Anuga *et al*., 2019; Wang *et al*., 2016). To calculate the amount CO_2 sequestered by an annual crop (i.e., sesame) includes determination of total green weight, dry weight, C content and CO_2 sequestered by the crop plant as in standard IPCC protocol (Albrecht and Kandji, 2003; Wang *et al*., 2016). Determination of total green weight was based on the algorithm to calculate the weight (g) of average 30±2 plant (Plant density=30±2 plant/m^2) for both above and below-ground biomass of the crop plant. A dry weight conversion factor (DWCF) for the crop plant was determined by using their moisture content (%) to determine the dry weight (DW) in g/plant. The weight of C (CW) was determined through multiplying the DW of the crop plant (g/plant) by the average C content (46%) of the plant. The CO_2 sequestered was determined through multiply the CW in the crop plant by 3.67 (Ratio of CO_2 to C) (Albrecht and Kandji, 2003; Lal, 2008, 2011).

Statistical Analysis: Experimental data of different phytoconstituents of the selected crop (sesame and green gram) cultivars and the pest (*S. obliqua*) population parameters along with their feeding indices were subjected to one-way Analysis of Variance (ANOVA) and correlation analysis (Zar, 1999). The field experiment (RBD) data of the selected crops and the RQS data from the field with ETL values of the pest were also analysed by using one-way ANOVA (Zar, 1999). Means of different phytoconstituents of the selected crops, demographic parameters and different feeding indices of the pest along with ET related values were compared by Tukey's test (HSD) when significant values were obtained (Roy, 2017). All the statistical analysis was performed by using SPSS, version 16.0 (Roy 2017, 2019).

RESULTS

Host Phytochemicals: The biochemical constituents of the selected crop cultivars (sesame and green gram) are presented in fig. 1(A,B). The primary metabolites i.e., carbohydrates, proteins, lipids and amino acids (total, free and bound) including nitrogen, moisture content, alkanes and fatty acids varied significantly ($P < 0.05$) in the selected crop cultivars (sesame>green gram). Total carbohydrate, protein and lipid contents were 52.157±0.514, 8.357±0.334, 6.957±0.214 and 51.941±0.465, 8.141±0.246, 6.767±0.302 µg/mg dry weight, respectively, in the selected host cultivars (sesame>green gram). The secondary metabolites were almost reverse in the crops (sesame<green gram) cultivar with significant ($P < 0.05$) differences (Fig. 1A). Total phenol, flavonoid, tanin and phytate contents were12.387±0.654, 11.347±0.463, 7.227±0.343, 5.027±0.231 and 13.126±0.543, 12.086±0.542, 8.499±0.434, 6.299±0.354 µg/mg dry weight, respectively, in the selected crops (sesame<green gram) cultivar. Ultimately, the ratio of primary to secondary metabolites significantly ($P < 0.05$) varied in the selected crops cultivar.

Feeding ecology: The food utilization indices were calculated only for the caterpillars of *S obliqua* as they only feed the plants and ultimately lead to the variation in their life history and other population parameters. The food utilisation efficiency of *S. obliqua* larvae significantly ($P<0.05$) varied on the selected crops cultivar. The average GR and CR were 7.148±4.722, 39.944±13.267 and 6.730±4.402, 33.484±11.429 mg/day, respectively, for the crops (sesame> green gram) cultivar which varied significantly ($F_{5,17}\leq72013.881$; $P<0.001$). Whereas, the average AD and HUE were 72.355±6.639, 79.393±4.061 and 69.318±7.057, 77.627±4.117%, respectively, for the crops (sesame> green gram) (Table 1) which also varied significantly ($F_{5,17}\leq17049.041$; $P<0.001$). Even, average GI and PSI (%) were 4.041±0.043, 62.838±2.904 and 3.405±0.073, 58.774±1.904%, respectively, for the crops (sesame> green gram) which varied significantly ($F_{1,4}\leq8.239$; $P<0.05$) whereas FI on the selected host plants also varied similarly as GI. Thus, the feeding indices along with host susceptibility (PSI%) of *S. obliqua* represent biotic resistance to green gram relative compared to the sesame cultivar which might due to their respective phytoconstituents (Table 1).

Population dynamics: The stage-specific two-sex pooled life tables of *S. obliqua* were assessed in the laboratory with three replications on mature leaves of sesame and green gram during 2019.The pest exhibited four distinct stages (i.e., egg, larva, pupa and adult) with six larval instars on the selected crops.The demographic data of the cohorts (3×2=6; n=100 eggs) of *S. obliqua* represent similar pattern of development with significant variations ($P<0.001$) in different developmental stages on the crops (Table 2-5). The population parameters like, l_x, L_x, T_x and e_x of *S. obliqua* were higher throughout their developmental stages with significant ($F_{7,6}\leq170.784$; $P < 0.001$) variations on sesame than green gram and they always produce type-III survivorship curve like most of the insects. However, the d_x, q_x and k_x varied in different developmental stages with significant ($P < 0.001$) variations and comparatively higher in egg and pupal stage with a rapid surge during adult stage on green gram than sesame. ANOVA results of the life table parameters on the selected crop cultivars revealed more or less same pattern on the host plants with significant variations ($F_{7,16}$=170.784-3876.337; $P<0.0001$) (Table 4).

The average Pf were 288.667±9.528 and 256.583 ± 8.513 eggs/female/generation, respectively for sesame and green gram. The Pf, GRR or m_x and NRR or R_0 of *S obliqua* were showed no significant variations. Whereas, average DT were 8.137±0.228 and 16.033±2.334, respectively (Table 5) for the crops (sesame< green gram) cultivar with significant variations ($F_{1,4}$=9.917; P=0.032). The r_m and ë were 0.085±0.002, 1.089±0.003 and 0.070±0.006,1.073±0.006, respectively (Table 5) for the crop cultivars (sesame>green gram) with significant variations ($F_{1,4}$=9.226-9.296; P=0.038). The average GM, GS, PGR, PMF, CBR, VI and TI of *S obliqua* were also without significant variations ($F_{1,4}$=0.071-0.99; $P>0.05$) like remaining other parameters (Table 5) on the selected crop.

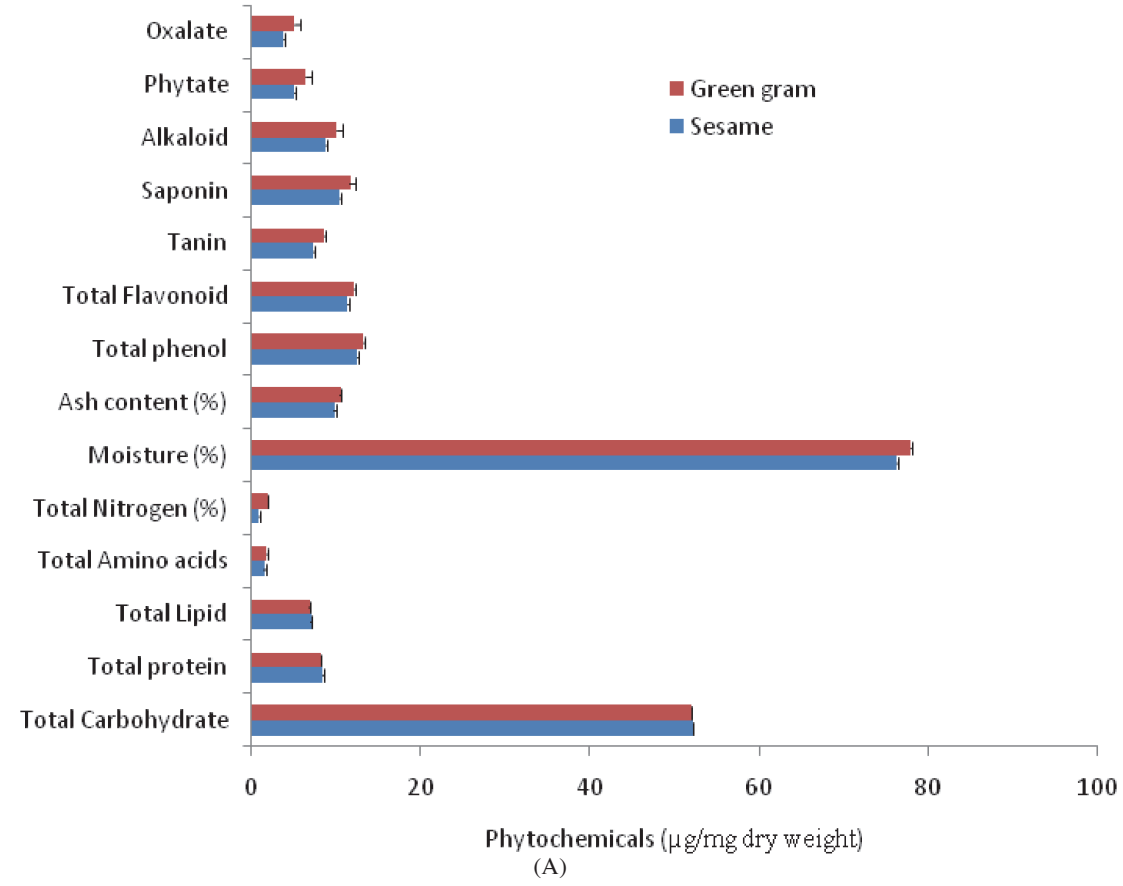

Fig. 1 Phytochemical constituents of sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54). All the estimated chemicals (Mean ± SE of 3 observations) significantly differed at P< 0.05 by Tukey (HSD) test

Table 1. Growth parameters (Mean ± SE of 3 observations) of *S. obliqua* Walkar on sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54)

Parameter	Sesame	Green gram	$F_{5,17}$	Sig.
GR (mg/day)	7.148±4.722	6.730±4.402	72013.881	0.001
CR (mg/day)	39.944±13.267	33.484±11.429	85728.873	0.001
RGR (mg/day)	2.973±0.817	3.405±0.914	16220.850	0.001
CI (mg/day)	55.768±25.144	55.570±25.426	11854.754	0.001
AD (%)	72.355±6.639	69.318±7.057	17049.041	0.001
ECI (%)	10.711±5.163	12.143±5.681	10711.912	0.001
ECD (%)	16.644±7.829	20.074±9.239	40273.263	0.001
HUE (%)	79.393±4.061	77.627±4.117	17458.856	0.001
ER (mg/day)	15.254±8.666	17.458±10.065	56607.732	0.001
HCR (mg/day)	71.022±32.835	73.028±34.609	20122.187	0.001
Parameter	Sesame	Green gram	$F_{1,4}$	Sig.
FI	0.010±0.000	0.011±0.000	10.276	0.033
GI	4.041±0.043	3.405±0.073	13.857	0.020
PSI%	62.838±2.904	58.774±1.904	8.239	0.031

Within the rows means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test along with *F* values (ANOVA).

Table 2. Stage-specific pooled life table (Mean ± SE of 3 observations) for 3 cohorts (n=100) of *S. obliqua* Walker on sesame (*S. indicum*; cv. Rama)

Stage	l_x	d_x	q_x	s_x	L_x	T_x	k_x	e_x
Egg-0	1.000±0.000	0.125±0.004	0.125±0.004	0.875±0.004	0.938±0.002	6.955±0.101	0.058±0.002	6.955±0.101
Inst- I -1	0.875±0.004	0.038±0.001[a]	0.044±0.002[a]	0.956±0.002[a]	0.856±0.005	6.018±0.099	0.019±0.001[a]	6.877±0.080
Inst- II-2	0.837±0.005	0.038±0.001[a]	0.046±0.002[a]	0.954±0.002[a]	0.818±0.006	5.162±0.094	0.020±0.001[a]	6.167±0.073
Inst- III-3	0.799±0.007	0.049±0.002	0.061±0.003[b]	0.939±0.003[b]	0.774±0.007	4.344±0.088	0.027±0.001[b]	5.438±0.065
Inst- IV-4	0.750±0.008	0.052±0.002	0.070±0.003	0.930±0.003	0.724±0.009	3.570±0.080	0.031±0.001	4.758±0.055
Inst- V-5	0.698±0.010	0.042±0.001	0.060±0.003[b]	0.940±0.003[b]	0.677±0.011	2.846±0.071	0.027±0.001[b]	4.076±0.044
Inst- VI-6	0.656±0.011	0.066±0.002	0.101±0.005	0.899±0.005	0.623±0.012	2.169±0.061	0.046±0.002	3.303±0.035
Prepup-7	0.590±0.014	0.014±0.000	0.024±0.001	0.976±0.001	0.583±0.014	1.545±0.048	0.010±0.001	2.617±0.022
Pup-8	0.576±0.014	0.076±0.003	0.133±0.008	0.867±0.008	0.538±0.015	0.962±0.034	0.062±0.004	1.668±0.019
Adult-9	0.500±0.017	0.153±0.005	0.307±0.020	0.693±0.020	0.424±0.019	0.424±0.019	0.160±0.013	0.847±0.010

Within the column means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test

Thus, all the 25 selected population parameters of *S. obliqua* were showed more or less insignificant (*P*>0.05) variations with few deviations on the selected crops (sesame> green gram) cultivar (Table 5). Thus, host superiority or susceptibility (sesame> green gram) in respect to their phytoconstituents (Fig. 1A,B) also influence the notorious pest in their population growth and reproductive parameters.

Yield loss and Crop productivity parameters: Yield loss in sesame and green gram and ET for *S obliqua* were assessed in the field condition against a traditional synthetic pesticide (Triazophos 40 EC) over control (without any pesticide) during summer season (February to June) in 2019 (Table 6). The damage (D%) per pest (*S obliqua*) per plant were 5.392±0.443 and 4.619±0.028%, respectively on the cultivars(sesame>green gram) without significant

($F_{1,4}$=2.894; P=0.169) differences (Table 6). Average EIL and ET were 26.388±1.627, 24.230±2.412 and 29.907±1.917, 27.930±1.841 pest/30 plants, respectively for the selected crops (sesame< green gram) cultivar without any significant ($F_{1,4}$=2.794-3.335; P≤0.142) variation (Table 6). For a single pest/m^2 (30±2 plants/m^2) observation the possible time that can be taken to reach EIL (Ti) and ET (Tt) were arrived as 38.246±1.157, 37.246±1.157 and 50.132±2.746, 49.132±2.746 days, respectively on the selected crops (sesame< green gram) cultivar with significant ($F_{1,4}$=24.111; P=0.008) variation (Table 6). Even, ET based time series was also calculated to find the specific time (Tt days) to reach ET for any number of pest(s)on the selected crops The maximum tolerance levels of the pests were 22.200 and 25.800 insects per m^2 (30±2 plants/m^2), respectively on sesame and green gram (Table 7). The benefit cost ratio (BCR/ha) of sesame and green gram were 0.478 and 0.390, respectively with significant (P<0.05) deviation (Table 6).Thus, the yield loss and ET calculation also represent similar biotic resistance (sesame<green gram) and or susceptibility (sesame>green gram) of the host plants as in feeding as well as in population dynamics

Table 3. Stage-specific pooled life table (Mean ± SE of 3 observations) for 3 cohorts (n=100) of *S. obliqua* Walker on green gram (*V. radiata*; cv. KB-54)

Stage	l_x	d_x	q_x	s_x	L_x	T_x	k_x	e_x
Egg-0	1.000±0.000	0.151±0.003	0.151±0.003	0.849±0.003	0.924±0.001	6.349±0.073	0.072±0.001^a	6.349±0.073
lnst- I -1	0.849±0.003	0.046±0.001^a	0.055±0.001^a	0.945±0.001^a	0.826±0.003	5.424±0.072	0.025±0.001^b	6.347±0.056
lnst- II-2	0.803±0.004	0.046±0.001^a	0.059±0.001^a	0.941±0.001^a	0.780±0.004	4.598±0.068	0.027±0.001^b	5.673±0.050
lnst- III-3	0.756±0.005	0.059±0.001	0.081±0.002^b	0.919±0.002^b	0.727±0.005	3.819±0.064	0.037±0.001	4.981±0.044
lnst- IV-4	0.698±0.006	0.063±0.001	0.095±0.002	0.905±0.002	0.666±0.007	3.092±0.058	0.044±0.001^c	4.351±0.036
lnst- V-5	0.635±0.007	0.050±0.001	0.086±0.002^b	0.914±0.002^b	0.609±0.008	2.426±0.052	0.040±0.001^c	3.732±0.028
lnst- VI-6	0.584±0.008	0.080±0.002	0.154±0.003	0.846±0.003	0.544±0.009	1.816±0.044	0.075±0.002^a	3.016±0.022
Prepup-7	0.504±0.010	0.017±0.000	0.041±0.001	0.959±0.001	0.496±0.010	1.272±0.035	0.018±0.000	2.443±0.013
Pup-8	0.488±0.010	0.092±0.002	0.242±0.005	0.758±0.005	0.441±0.011	0.776±0.025	0.143±0.002	1.519±0.011
Adult-9	0.395±0.012	0.122±0.004	0.301±0.011	0.699±0.011	0.334±0.014	0.334±0.014	0.178±0.006	0.850±0.006

Within the column means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test

Table 4. Stage-specific pooled life table for the six cohorts (n=100) of *S. obliqua* Walkar on sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54)

Developmental stages	Sesame	Green gram	*Sig.*
	$F_{7,16}$	$F_{7,16}$	
Egg-0	3540.022	3051.643	0.0001
lnst- I -1	3876.337	3326.806	0.0001
lnst- II-2	3411.683	2919.135	0.0001
lnst- III-3	2963.365	2527.338	0.0001
lnst- IV-4	2664.170	2266.508	0.0001
lnst- V-5	2456.039	2087.538	0.0001
lnst- VI-6	2067.495	1752.255	0.0001
Prepup-7	2102.920	1799.046	0.0001
Pup-8	1148.710	963.127	0.0001
Adult-9	221.232	170.784	0.0001

Table 5. Population dynamics and reproductive parameters (Mean ± SE of 3 observations) of *S. obliqua* Walker on sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54)

Population parameters	Sesame	Green gram	$F_{1,4}$	Sig.
Potential fecundity (Pf)	288.667±9.528	256.583±8.513	6.047	0.070
Total fertility rate (F_x)	11696.267±1482.325	9529.233±1276.552	6.085	0.069
Gross reproductive rate (GRR) m_x	80.193±5.349	71.924±5.947	5.715	0.075
Net reproductive rate (NRR) R_0	40.267±3.811	31.644±3.801	6.047	0.070
Generation time (T_c)	43.215±0.101	44.206±0.248	1.648	0.269
Doubling time (DT)	8.137±0.228	16.033±2.334	9.917	0.032
Intrinsic rate of increase (r_m)	0.085±0.002	0.070±0.006	9.226	0.038
Euler's corrected r (r_c)	0.037±0.003	0.059±0.009	3.858	0.121
Finite rate of increase (ë)	1.089±0.003	1.073±0.006	9.296	0.038
Weelkly multiplication rate ($ë^7$)	1.817±0.030	1.655±0.058	9.685	0.036
Annual rate of increase (ARI) ($ë^{365}$)	6.02E+13	7.91E+14±2.6E+14	2.415	0.195
Increase rate per generation ($ë^{Tc}$)	40.267±3.811	31.644±3.801	6.047	0.070
Generation mortality (GM)	0.461±0.027	0.659±0.098	4.582	0.099
Mortality coefficient (MC)	0.139±0.010	0.109±0.012	5.686	0.076
Generation survival (GS)	0.571±0.016	0.456±0.029	5.593	0.077
Population growth rate (PGR) (r_mN)	8.633±1.046	6.727±0.884	7.072	0.056
Population momentum factor of increase (PMF)	14.695±0.637	16.327±1.239	6.086	0.069
Population size in 2nd generation (PMF_xN)	1491.388±203.564	1281.499±189.710	6.344	0.065
Hypothetical F_2 females (HNf_2)	1650.453±251.697	1470.311±241.114	5.915	0.072
Realised F2 females (RNf_2)	596.555±81.425	512.599±75.884	6.344	0.065
General fertility rate (GFR)	7.255±0.458	17.523±7.311	3.366	0.140
Crude birth rate (CBR)	1.433±0.025	1.626±0.052	5.368	0.081
Reproductive value (RV)	160.387±9.970	143.848±11.947	5.715	0.075
Vital Indwx (VI)	0.347±0.022	0.273±0.030	5.686	0.076
Trend index (TI)	52.504±4.485	41.415±4.874	5.980	0.071

Within the rows means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test along with *F* values (ANOVA).

of *S. obliqua* due to variation in their respective phytoconstituents (Fig. 1A,B).The carbon sequestration efficiency of sesame (301.860kg/ha) was significantly (P<0.05) higher than green gram (172.260 kg/ha) due to more biomass production (Table 6). It will also support climate smart pest management (CSPM) strategy of the crops.

DISCUSSION

In the modern era of climate smart agriculture (CSA) as well as CSPM,use of irradiated sterile insects (male), genetically engineered pests (mutant male) and pest pheromones (lure for male) in mating disruption are most effective pest management strategy other than use of pest resistant crop cultivars to avoid or reduce the adverse effects of broad spectrum synthetic pesticides (Alphey, 2007; Witzgall *et al*., 2010; Heeb *et al*., 209; Kang, 2019), while population ecology based ETs determination and time series calculation is also a widely useful technique for ecological pest management (EPM) as a part of IPM (Southwood, 1978; Carey, 2001; Kakde *et al*., 2014; Chávez *et al*., 2018; Roy, 2019).

Pest ecology and host preference based studies are common to cope with the pest infestation in IPM or rather EPM for better crop production (Dicke, 2000; Schoonhoven *et al*., 2005; Roy and Barik, 2013; Roy, 2019). Host plant availability and quality in terms of their phytochemicals play a vital role in pest feeding preference as well as population dynamics by affecting immature and adult performance (Shobana *et al*., 2010; Roy and Barik, 2012). Variation in the results of this study could be attributed to differences among nutritional and anti-nutritional factors present in the respective crops (sesame and green gram) cultivar directly affect host preference and population parameters of *S. obliqua* as in other findings (Awmack and Leather, 2002; Syed and Abro, 2003; Xue *et al*., 2010; Roy and Barik, 2013; Dutta and Roy, 2016).The overall survival rate of *S. obliqua* on sesame leaves was higher than on green gram leaves and the result suggest type III survivourship curve like most other insect pests (Price, 1998; Roy, 2015b; Dutta and Roy, 2016). The GRR, R0, rm, Tc, DT and λ are fundamental ecological parameters to predict the pest population growth to evaluate the performance of an insect on different host plants as well as their resistance or susceptibility (Southwood and Henderson, 2000; Win *et al*., 2011; Roy, 2015b; Dutta and Roy, 2016; Roy, 207). In my current study, the variations in life table parameters of *S. Obliqua* is due to variation in primary and

Table 6. Yield loss and crop productivity parameters of sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54) due to *S. obliqua* infestation

Crop Parameter	Sesame	Green gram	$F_{1,4}$	Sig.
Yield damage without treatment (Yd %)	22.585±2.661	23.897±0.049	0.262	0.636
Proportion of insect controlled (PC %)	75.000±4.811	80.300±0.449	1.008	0.372
Yield damage reduction after treatment (Yr %)	17.193±3.104	19.279±0.022	0.461	0.535
Damage per pest per plant (D%)	5.392±0.443	4.619±0.028	2.814	0.169
EIL (pests/30 plants)	26.388±1.627	29.907±1.917	2.794	0.170
ETL (pests/30 plants)	24.230±2.412	27.930±1.841	3.335	0.142
EEIL(pests/30 plants)	26.415±2.630	29.938±1.919	2.794	0.170
Time to reach EIL/pests/30 plants (Ti days)	38.246±1.157	50.132±2.746	24.111	0.008
Time to reach ETL/pests/ 30 plants (Tt days)	37.246±1.157	49.132±2.746	24.111	0.008
Production values				
Seed Yield [SY] (kg/ha)	788.172	741.471	-	-
Production cost [C] (Rs/ha)	22400.000	22400.000	-	-
Economic yield [EY](Rs/ha)	33103.205	31141.767	-	-
Net Profit [NP] (Rs/ha)	10703.205	8741.767	-	-
Benefit cost ratio (BCR/ha)	0.478	0.390	-	-
Carbon sequestration efficiencies				
Plant density (number/m^2)	30±2	30±2	-	-
Biomass produced (kg dry wt/ m^2)	0.060	0.034	-	-
Carbon sequestration (kg/ m^2)	0.030	0.017	-	-
Equivalent CO2 sequestration (kg/ m^2)	0.111	0.063	-	-
Carbon sequestration (kg/ha)	301.860	172.260	-	-
Equivalent CO2 sequestration (kg/ ha)	1106.820	631.620	-	-
Equivalent CO2 sequestration (Tons/ ha)	13.423	7.660	-	-

Within the column means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test along with *F* values (ANOVA).

Table 7. Time Series assessment of ET at varied pest density (*S. obliqua*) on sesame (*S. indicum*; cv. Rama) and green gram (*V. radiata*; cv. KB-54)

Pest(s)/m^2	Tt (days) for Sesame	Tt (days) for Green gram
0.025	80.653	99.613
0.05	72.523	89.775
0.1	64.393	79.938
0.2	56.264	70.100
0.3	51.508	64.345
0.4	48.134	60.262
0.5	45.517	57.095
0.6	43.378	54.508
0.7	41.570	52.320
0.8	40.004	50.425
0.9	38.623	48.753
1	37.387	47.258
.....up to ETLe"1 day remain for manage the pest		
MTL (Pests/m^2)	22.200	25.800

MTL (Maximum tolerance level)

secondary metabolites of respective host plants which is also supported by host preference or resistance or vice versa.

Pest population ecology and their ETs for any appropriate pest management strategy is a part of IPM or EPM (Pedigo and Higley, 1992; Roy, 2019). The EIL and ET is generally calculated by linear regression model (y= ax+c) based on yield loss, degree of pest infestation, Pest population growth, cost of protection and market price of the crop (Pedigo and Higley, 1992). A low EIL and ET of *S. obliqua* was found in sesame than green gram due to high damage potential of the pest on their respective preferred host plantsas in other findings (Pedigo and Higley, 1992; Roy, 2019). Thus, this study suggests that sesame possessed relatively rich food quality for *S. obliqua* than green gram leading to higher level of leaf consumption and crop damage resulting in more susceptibility or less resistance indicating the chance of utilization of sesame as a trap crop for green gram. Even, ETs based time series for judicious application of any sustainable control measures against this pest under the arena of CSPM as well as carbon sequestration efficiency of the crops will reduce ecological imbalance to promote CSA of such crops in near future.

There is a worldwide growing awareness for promoting environmentally benign and ecosystem service (ESS) based CSPM practices for CSA. Even ecological engineering (EE) by tailoring ESS manipulation is crucial for better production of any crop. These approaches would bring down the pest load below ETL by judicial use of any control measures including broad-spectrum pesticides for sustainable agriculture. In respect to the phytochemical regime, sesame leaves had the lowest antibiosis resistance than green gram against *S. obliqua* as indicated by the short developmental time and high survival of their immature stages which will enable growers to use sesame as a trap crop for green gram along with their respective ETs for most appropriate control tactics towards CSPM. Even, it will also supportE^3 (Ecosystem service based Ecological engineering for Ecological pest management [ESS-EE-EPM]) pest management strategy with Triple-E (ecological, environmental

and economical) sustainability for the generalist pest, *S obliqua*, to promote CSPM for better cultivation of such crops in near future.

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Host plants of the home invading nuisance pest, Mupli beetle, *Luprops tristis* (Fabricius, 1801) (Coleoptera: Tenebrionidae) in agribelts of south India

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ABSTRACT: Presence of home invading nuisance pest *Luprops tristis* (Fabricius, 1801) in non-rubber belts and its generalist feeding behavior lead to assessment of its feeding preference on the leaves of common litter contributing plants in agribelts in south India. Bioassays with leaves of 17 plants namely, cashew, cassia, cocoa, flowering murdah golden flame tree, Indian-beech, Indian kino, jackfruit, macaranga, mahogany, mango, mexican lilac, raintree, rubber, tamarind, teak and wild jack were carried out. General bias towards tender leaves of most plants was distinct. Based on Leaf age related variation in feeding rates, host plant were categorised as tender leaf preferred, both tender and senescent leaves preferred and senescent leaf preferred. Based on leaf consumption rates, host plants were broadly categorized as most preferred, moderately preferred, low preferred and least preferred, and its implications are discussed. Aggressive feeding on leaves of many plants abundant in non-rubber agriculture belts necessitates their monitoring in the litter stands of the cited plants in non-rubber belts for preventing its establishment as uncontrollable nuisance pest across south India. © 2020 Association for Advancement of Entomology

KEY WORDS: rubber litter beetle, feeding preference, implications

INTRODUCTION

Massive home invasion of the litter dwelling darkling beetle, *Luprops tristis* (Fabricius, 1801), regionally referred to as "Mupli vandu", "Ola prani", "Ola chathan", "Otteruma" or "Karinchellu", following summer showers is a regular event in the rubber plantation belts of south India. High abundance in the range of 0.5 to over 4 million per residential building, active nocturnal movements, aggregation in a state of dormancy inside residential buildings extending upto 6-8 months and release of an odoriferous glandular secretion causing skin burn and eye inflammation makes *L. tristis,* a serious nuisance pest in rubber plantation belts. Litter stands of monoculture rubber plantations are the major breeding and feeding habitat of *L. tristis* in the region with wilted tender rubber leaves [*Hevea brasiliensis,* (Willd. ex Adr. De Jus) M¨ull. Arg. 1865] as the preferred food resource (Sabu et al. 2008). Availability of the nutritionally superior prematurely fallen tender leaves of rubber tree as food resource and perfect synchronism of its life cycle with the leaf phenology of rubber tree has lead to exceptionally high abundance of *L. tristis* in rubber plantation belts (Sabu and Vinod, 2009 a, b;

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Sabu *et al*., 2013). Fallen leaves of cocoa (*Theobroma cacao* Linnaeus, 1753) and jackfruit (*Artocarpus heterophyllus* Lamarck, 1789) are the major alternate food sources of *L. tristis* in rubber plantation belts (Sabu *et al*., 2012).

Presence of *L. tristis* infestation in non-rubber, non-jackfruit, and non-cocoa belts in many regions of south India (personal observations) and the dry eastern slope of the south Western Ghats (Sabu *et al*., 2007), home invasion in north Malabar region even before the introduction of rubber plantations (Beeson, 1941) and its generalist feeding nature (Sabu *et al*., 2012) indicate that *L. tristis* can sustain on the leaf litter of many other plants and is not confined to rubber belts alone. Considering its generalist and detritivorous feeding habits (Sabu *et al*., 2008), preference for tender leaves (Sabu and Vinod, 2009 b; Sabu *et al*., 2012) and presence in non-rubber belts, it is hypothesized that *L. tristis* can feed on both tender and senescent leaves of shade trees, plantation crops and trees maintained for fodder for domesticated mammals, green manure, and fruits in south India. Data generated would be helpful in identifying the host plants and breeding habitats of *L. tristis* in non-rubber regions where its host plants remain unknown and in controlling the spread of the beetle into new regions at the outset.

MATERIALS AND METHODS

Study was carried out during March–April 2013 at Department of Zoology, St. Joseph's College, Devagiri, Calicut, Kerala (India). To ensure uniformity of age at the beginning of the experiment, teneral adults of *L. tristis* were collected based on their brownish white body colour (Sabu et al. 2008) from the rubber plantation litter in the Devagiri College campus, located 6 km east from the Malabar Coast at Kozhikode (11°16'12.9"N 75°49'48.108"E), in the Kerala state of India. Collected beetles were reared in clay vessels (13 x 35 cm) placed in an environmental chamber (YORCO, India) at relative humidity 70% and temperature 33ºC (representing the average temperature and humidity in the rubber plantation litter) and fed with a mixture of diced tender and senescent leaves of the 17 leaf types for 10 days to reduce the possible effect of leaf quality variations on growth rate and feeding preference. Beetles were deprived of food for 24 hrs before starting the feeding experiments. List of the plants analysed are cashew (*Anacardium occidentale,* Linn. 1753; Anacardiaceae, Sapindales), cassia (*Cassia fistula,* Linn. 1753; Fabaceae, Fabales), cocoa (*Theobroma cacao,* Linn. 1753; Malvaceae, Malvales), flowering murdah (*Terminalia paniculata* Roth. 1821; Fabaceae, Fabales), golden flame tree (*Peltophorum pterocarpum* (DC.) Baker ex K. Heyne 1927; Fabaceae, Fabales), Indian-beech (*Pongamia pinnata* (L.) Pierre 1899; Fabaceae, Fabales), Indian kino (*Pterocarpus marsupium* Roxb. 1795; Fabaceae, Fabales), jackfruit (*Artocarpus heterophyllus,* Lam. 1789; Moraceae, Rosales), macaranga (*Macaranga peltata* Müll.Arg. 1866; Euphorbiaceae, Malpighiales), mahogany (*Swietenia mahagoni* (L.) Jacq. 1760; Meliaceae, Sapindales), mango (*Mangifera indica,* Linn. 1753; Anacardiaceae, Sapindales), mexican lilac (*Gliricidia sepium* (Jacq.) Kunth 1842; Fabaceae, Fabales), raintree (*Albizia saman* (Jacq.)Merr. 1891; Fabaceae, Fabales), rubber [*Hevea brasiliensis* (Willd. ex Adr. De Jus) M¨ull. Arg. 1865; Euphorbiaceae, Malpighiales], tamarind (*Tamarindus indica* L. 1753; Fabaceae, Fabales) teak (*Tectona grandis* Linn. 1781; Verbinaceae, Lamiales) and wild jack (*Artocarpus hirsutus* Lam. 1789; Moraceae, Rosales). Tender and senescent leaves of the host plants were collected from non-rubber agriculture landscape at Chelavoor (11º30 N, 75º84 E) close to Calicut. Freshly sprouted leaves of five to ten days of age (identifiable by smaller size, smooth texture, and bright green or brown colour) were categorised as tender leaves and were collected from the tree branches of same height. Senescent leaves that are yellowish brown in colour were removed by a gentle flicking of the leaf from the trees. Collected leaves were brought to the laboratory and leaf discs (900 mm^2) of each leaf type were prepared and kept under ambient conditions for 24 h. For host plants like *P. pterocarpum* and *T. indica* where compound leaves with small leaflets are present, 18 small leaf discs (0.5cm^2) were used instead of a single leaf disc.

Experiment set up:

Food preferences were analysed with multiple choice and two choice leaf disc tests in the second week of March 2013 on successive days. Feeding preference towards tender and senescent leaves (two choice leaf disc tests: hereafter referred as no choice tests as it involves a single host plant) were carried out for 10 host plants namely, Flowering murdah (*Terminalia paniculata* Roth. 1821), Indian kino (*Pterocarpus marsupium* Roxb. 1795), Mahogany (*Swietenia mahagoni* (L.) Jacq. 1760), Macaranga (*Macaranga peltata* Müll.Arg. 1866), Golden flame tree (*Peltophorum pterocarpum* (DC.) Baker ex K. Heyne 1927), Mexican lilac (*Gliricidia sepium* (Jacq.) Kunth 1842), Indian-beech *(Pongamia pinnata* (L.) Pierre 1899), Raintree (*Albizia saman* (Jacq.)Merr. 1891), Teak (*Tectona Grandis* Linn. 1781) and Tamarind (*Tamarindus indica* Linn. 1753) and for seven host plants, namely Rubber [*Hevea brasiliensis,* (Willd. ex Adr. De Jus) M¨ull. Arg. 1865], Cashew (*Anacardium occidentale,* Linn. 1753), Mango (*Mangifera indica,* Linn. 1753), Jackfruit (*Artocarpus heterophyllus,* Lam. 1789), Wild jack (*Artocarpus hirsutus,* Lam. 1789), Cocoa (*Theobroma cacao,* Linn. 1753) and Cassia (*Cassia fistula,* Linn. 1753), data from the earlier study (Sabu et al. 2012) was used. Multiple choice leaf disc tests with tender and senescent leaf age classes were conducted for all the 17 host plants. Leaf discs (900 mm^2) of each leaf type were cut and were individually marked with stapler pins (one stapler pin on leaf type 1; 2 pins parallel to each other on leaf type 2; 2 pins crosswise on leaf type 3; 3 pins parallel to each other on leaf type 4, and so on) that enabled their identification. For no choice tests, one tender and one senescent leaf disc of each host plant was placed in a clay vessel (9 cm diameter × 5 cm height). For multi choice tests, one leaf disc of each host plant was loosely attached with a labelled pin to a thermocol sheet placed inside a clay vessel (15 cm diameter × 35 cm height) for both tender and senescent leaf age class separately. A distance of 5 mm between adjacent leaf discs was maintained. In no-choice experiments, three teneral beetles and in multiple-choice experiments nine teneral beetles were introduced into the centre of the vessel and allowed to feed for 24 h (8 am to 8 am). Based on the average food consumption of *L. tristis* (Sabu *et al*., 2012), introduction of three beetles for 17 host leaves would have resulted in satiation with a few host leaves and avoiding the others. Fifteen replicates were maintained for each host plant in no choice experiments and for each leaf age class in multi choice experiment. Leaf area consumed was estimated using a 1 mm^2 mesh size-reticulated paper glued on a glass slide. Amount of leaf disc consumed during the tests was estimated by subtracting the unconsumed area from the initial area of 900 mm^2 (Sabu *et al*., 2012).

Data Analysis:

Significance levels of variation in the quantity of leaf consumed among the leaf types and leaf ages were assessed with two-way ANOVA and pair wise differences among leaf types with Tukey-Kramer post hoc tests (*t* tests). Significance level of the variation in the quantity of leaf consumed between the tender and senescent leaves of each leaf type was assessed with one-way ANOVA. Based on the quantum of leaves consumed in multichoice experiments, tender and senescent leaves of host plants with leaf consumption of >10 mm were broadly classified as most preferred; 4 to 10 mm as moderately preferred; 1 to < 4 mm as low preferred; and <1 mm as least preferred host plant categories. Feeding recorded in no choice experiment was used to analyse the preference towards tender and senescent leaf age classes for each host plant and to measure the extent to which the beetle will feed on each host plant leaf when other leaf resources were not available as in monoculture plantations. Plants were ranked in no choice and multi choice experiments based on comparison of the variation in quantum of leaves consumed individually in both tender and senescent leaf age classes. The preference hierarchy was reached by ranking the leaf types based on the significance level of the pair wise treatments for each host plant. All analyses were done following square root transformation of the data (Weiss, 2007). Significance was determined at $P < 0.05$. Means that differ significantly ($P \leq 0.05$) within tender and senescent leaf age classes are indicated as

differences in letters ([a-h]) attached to Mean±SD values. All statistical analyses were performed by using Minitab 16 Academic Software for windows (Minitab, 2010).

RESULTS

Quantity of leaf consumed by *L. tristis* varied among the different leaf types and leaf age classes in both no choice and multichoice experiments (Table 1, 2, and 3).

Tender-Senescent leaf preference: Analysis of feeding preference towards tender and senescent leaves of host plants revealed that tender leaves were preferred over senescent leaves for *P. marsupium*, *S. mahagoni*, *T. indica*, *P. pinnata*, *P. pterocarpum*, *H. brasiliensis*, *A. heterophyllus*, *A. occidentale*, *M. indica*, *A. hirsutus,* and *C. fistula*; senescent leaves were preferred over tender leaves for *G. sepium* and *T. grandis* and; both tender and senescent leaves were equally preferred for *M. peltata*, *A. saman*, *T. paniculata* and *T. cacao*. Comparison of tender leaf consumption in no choice tests showed that, tender leaves of *H. brasiliensis, A. heterophyllus,* and *T. cacao* were most preferred and tender leaves of *P. pterocarpum*, *T. grandis*, *S. mahagoni*, and *M. peltata* were the least preferred. Comparison of senescent leaf consumption in no choice tests revealed that senescent leaves of *H. brasiliensis* and *G. sepium* were the most preferred and senescent leaves of *T. indica*, *S. mahagoni,* and *P. pterocarpum* were the least preferred (Table 1).

Table 1. Quantity of tender and senescent leaves consumed (Mean±SD) by *Luprops tristis* in no choice experiments and ranking of host plants based on leaf consumption

Host plants	Tender leaves		Senescent leaves	
	Mean±SD	Rank	Mean±SD	Rank
*Hevea brasiliensis**	103.03±85.41[a]	1	48.40±41.10[a]	1
*Artocarpus heterophyllus**	125.33±83.61[a]	1	7.37±7.46[bc]	3
Theobroma cacao	76.93±56.68[a]	1	4.13±5.28[cde]	5
*Pongamia pinnata**	21.87±3.46[b]	2	1.15±1.03[efg]	8
*Tamarindus indica **	15.20±6.66[bc]	3	0.20±0.22[g]	10
*Gliricidia sepium**	14.55±8.53[bcd]	4	26.70±14.07[a]	1
*Pterocarpus marsupium **	13.43±6.99[bcd]	4	7.55±2.38[b]	2
*Artocarpus hirsutus **	13.13±8.80[bcd]	4	1.30±0.93[defg]	7
*Anacardium occidentale**	9.60±7.84[cde]	5	2.37±3.81[defg]	7
Terminalia paniculata	5.65±2.77[def]	6	6.05±6.37[bc]	3
*Mangifera indica**	3.93±4.92[efg]	7	1.77±2.07[defg]	7
*Cassia fistula**	6.37±10.84[efg]	7	4.25±3.92[fg]	9
Albizia saman	3.20±5.45[fg]	8	0.92±1.45[bcd]	4
*Swietenia mahagoni**	1.46±1.21[fg]	8	0.20±0.19[g]	10
*Peltophorum pterocarpum**	1.15±0.63[fg]	8	0.28±0.27[fg]	9
Macaranga peltata	1.20±1.47[fg]	8	1.70±1.46[def]	6
*Tectona grandis **	0.35±0.52[g]	9	3.20±1.96[cde]	5

Note: * indicate significant difference ($P \leq 0.05$) between tender and senescent leaves.

Difference in letters ([a-g]) attached to Mean±SD values indicates means that differ significantly ($P \leq 0.05$) within tender and senescent leaf age class category.

Table 2. Two-way ANOVA for feeding preference of *L. tristis* with respect to the leaf type and leaf age in no-choice and multiple-choice experiment tests

No choice					
Source	*SS*	*df*	*MS*	*F*	*p-value*
Leaf type	1,906.81	16	119.18	41.55	0
Leaf age	375.08	1	375.08	130.78	0
Leaf type × Leaf age	799.19	16	49.95	17.42	0
Error	1,365.24	476	2.87		
Multichoice					
Source	*SS*	*df*	*MS*	*F*	*p-value*
Leaf type	354.85	16	22.18	25.09	0
Leaf age	3.50	1	3.50	3.96	0
Leaf type × Leaf age	77.19	16	4.82	5.46	0
Error	270.54	306	0.88		

Table 3. Quantity of tender leaves consumed (Mean±SD) by *Luprops tristis* in multi choice experiments and categorisation and ranking of host plants based on tender leaf consumption

Host plant category	Host plants	Mean±SD	Rank
Most preferred (mean value ≥10 mm)	*Artocarpus heterophyllus*	15.33±4.95^{a}	1
	Hevea brasiliensis	22.20±8.66^{a}	1
Moderately preferred (mean value 4 ≥ 10 mm)	*Theobroma cacao*	6.93±5.46^{b}	2
	Pongamia pinnata	9.48±9.36^{b}	2
	Pterocarpus marsupium	8.88±2.43^{b}	2
	Gliricidia sepium	5.75±4.84^{bc}	3
Low preferred (mean value 1≥ 4 mm)	*Tamarindus indica*	3.30±3.11^{cd}	4
	Anacardium occidentale	2.95±3.07^{cde}	5
	Cassia fistula	3.25±3.74^{cde}	5
	Mangifera indica	2.83±3.08^{cde}	5
	Artocarpus hirsutus	2.80±2.82^{cde}	5
	Terminalia paniculata	1.58±2.01^{def}	6
	Albizia saman	1.50±1.74^{def}	6
Least preferred (mean value > 1 mm)	*Peltophorum pterocarpum*	0.73±0.97^{ef}	7
	Swietenia mahagoni	0.33±0.55^{f}	8
	Tectona grandis	0.05±0.11^{f}	8
	Macaranga peltata	0.33±0.46^{f}	8

Note: Difference in letters ($^{a\text{-}f}$) attached to Mean±SD values indicates means that differ significantly (P > 0.05)

Host plant preference and categorisation of host plants:

Based on tender leaf preference: Based on the analysis of tender leaf consumption, *H. brasiliensis* and *A. heterophyllus* fall under the category of the most preferred tender leaves; *T. cacao*, *P. pinnata*, *G. sepium,* and *P. marsupium* fall under the category of moderately preferred tender leaves; *A. occidentale*, *A. hirsutus*, *C. fistula*, *T. indica*, *M. indica*, *T. paniculata,* and *A. saman* fall under the category of low preferred tender leaves and *P. pterocarpum*, *T. grandis*, *S. mahagoni,* and *M. peltata*, fall under the category of the least preferred tender leaves. Based on the quantum of tender leaves consumed *H. brasiliensis* and *A. heterophyllus* were ranked first, *T. cacao*, *P. pinnata*, were ranked second and *G. sepium* third in preference hierarchy (Table 3).

Based on senescent leaf preference: *Hevea brasiliensis* and *G. sepium* fall under the category of most preferred senescent leaves; *T. paniculata*, *P. marsupium,* and *A. heterophyllus* under the category of moderately preferred senescent leaves; *T. cacao*, *T. grandis*, *A. hirsutus*, *M. indica*, and *A. saman* under the category of low preferred senescent leaves and *P. pinnata*, *P. pterocarpum*, *A. occidentale*, *C. fistula*, *S. mahagoni*, *M. peltata*, and *T. indica* under the category of least preferred senescent leaves. Based on the quantum of senescent leaves consumed *H. brasiliensis* and *G. sepium* were ranked first, *A. heterophyllus* second and *P. marsupium* third in preference hierarchy (Table 4).

DISCUSSION

Tender-senescent leaf preference of host plants:

Based on tender-senescent leaf preference of *L. tristis*, host plants fall under three broad categories namely: 1) plants whose tender leaves are preferred, 2) plants whose senescent leaves are preferred, and 3) plants whose tender and senescent leaves are equally preferred. Lack of quantitative data on the leaf chemical traits of tender and senescent leaves of the native trees limits the scope for interpretation. Preference towards tender leaves of 10 host plants in the agribelts namely, *H. brasiliensis, A. heterophyllus*, *P. pinnata*, *P. marsupium*, *A. hirsutus*, *M. indica*, *T. indica*, *P. pterocarpum*, *A. occidentale*, and *C. fistula*, in both no choice and multichoice experiments conforms to the record of the preference of *L. tristis* towards tender leaves (Sabu *et al*., 2012; Sabu and Vinod, 2009 b). Since host plant quality is a key determinant of potential and achieved fecundity of herbivorous insects (Awmack and Leather, 2002), tender leaves of *H. brasiliensis* are essential for attaining reproductive maturity, egg production, longevity, and storage of fat reserves for the impending prolonged dormancy of *L. tristis* (Sabu *et al*., 2013; Vinod and Sabu, 2010); preference of *L. tristis* towards tender leaves is attributed to the high nutrient status of tender leaves of the host plants. Translocation of mobile nutrients from senescing leaves to new tissue by nutrient resorption which occurs at higher rates in deciduous trees and lower rates in evergreen trees makes tender leaves superior in nutrient quality over their senescent leaves (Aerts, 1996; Wright and Westoby, 2003, Vergutz *et al.,* 2012). In addition, considering the role of leaf toughness and waxiness in determining the feeding preference of herbivorous insects (Howe and Schaller, 2008; Xiang and Chen, 2004), preference towards the soft and non-glossy tender leaves over the hard, glossy senescent leaves might have contributed to the greater feeding on tender leaves.

In spite of the low nutrient quality of senescent leaves of deciduous trees (Aerts, 1996; Newbery *et al*., 1997; Wright and Westoby, 2003; Vergutz *et al.,* 2012), preference towards senescent leaves of deciduous *G. sepium* and *T. grandis* over their tender leaves indicates that some factor other than leaf nutrient quality repel *L. tristis* from feeding on their tender leaves. High nitrogen (N) content in senescent leaves resulting from the reduced nutrient resorption rates in N fixing plants (Eckstein *et al*., 1999; Norris and Reich, 2009; Vergutz *et al*., 2012) might be leading to higher feeding of *L. tristis* on senescent leaves of *G. sepium*. Preference of *L. tristis* towards senescent *T. grandis* leaves is in contrast to the preference of most insect pests to

Table 4. Quantity of tender and senscent leaves consumed (Mean±SD) by *Luprops tristis* in multi choice experiments and categorisation and ranking of host plants based on leaf consumption

Host plant/ Leaf category	Tender leaves			Sensecent leaves		
	Host plants	Mean±SD	Rank	Host plants	Mean±SD	Rank
Most preferred (mean value >10 mm)	*Artocarpus heterophyllus*	15.33±4.95[a]	1	*Hevea brasiliensis*	22.20±8.66[a]	1
	Hevea brasiliensis	12.90±4.74[a]	1	*Gliricidia sepium*	15.18±7.94[a]	1
Moderately preferred (mean value 4≥10 mm)	*Theobroma cacao*	6.93±5.46[b]	2	*Artocarpus heterophyllus*	6.78±5.28[b]	2
	Pongamia pinnata	9.48±9.36[b]	2	*Pterocarpus marsupium*	6.13±6.49[bc]	3
	Pterocarpus marsupium	8.88±2.43[b]	2	*Terminalia paniculata*	5.25±6.11[bd]	4
	Gliricidia sepium	5.75±4.84[bc]	3	*Theobroma cacao*	3.43±3.75[cde]	5
Low preferred (mean value 1 ≥4 mm)	*Tamarindus indica*	3.30±3.11[cd]	4	*Atrocarpus hirsutus*	1.48±1.20[def]	6
	Anacardium occidentale	2.95±3.07[cde]	5	*Albizia saman*	2.90±4.06[def]	6
	Cassia fistula	3.25±3.74[cde]	5	*Tectona grandis*	1.45±1.40[ef]	7
	Mangifera indica	2.83±3.08[cde]	5	*Mangifera indica*	1.15±1.74[fg]	8
	Artocarpus hirsutus	2.80±2.82[cde]	5	*Anacardium occidentale*	0.45±0.44[fg]	8
	Terminalia paniculata	1.58±2.01[def]	6	*Cassia fistula*	0.56±0.75[fg]	8
	Albizia saman	1.50±1.74[def]	6	*Macaranga peltata*	0.23±0.40[g]	9
Least preferred (mean value >1 mm)	*Peltophorum pterocarpum*	0.73±0.97[ef]	7	*Swietenia mahagoni*	0.03±0.08[h]	10
	Swietenia mahagoni	0.33±0.55[f]	8	*Pongamia pinnata*	0.13±0.27[h]	10
	Tectona grandis	0.05±0.11[f]	8	*Tamarindus indica*	0.10±0.17[h]	10
	Macaranga peltata	0.33±0.46[f]	8	*Peltophorum pterocarpum*	0.08±0.12[h]	10

(Note : Difference in letters ([a-h]) attached to Mean±SD values indicates means that differ significantly (P≥ 0.05) within tender and mature leaf age class category*)*

tender *T. grandis* leaves during the leaf flushing period (Basu *et al*., 2010). Hence what attracts *L. tristis* to senescent leaves of *T. grandis* requires special attention.

Equal preference of *L. tristis* towards tender and senescent leaves of *T. cacao*, *T. paniculata*, *A. saman,* and *M. peltata,* indicate that *L. tristis* can feed on both the leaves of these host plants. Low nutrient resorption rates from the senescent leaves in evergreen trees (Aerts, 1996; Wright and Westoby, 2003; Vergutz *et al*., 2012) that lead to lack of nutrient quality variation between tender and senescent leaves and the presence of some plant species specific secondary metabolites in the tender leaves (Howe and Schaller, 2008) could be the reason for equal preference towards tender and senescent leaves of the evergreen trees namely, *T. cacao*, *A. saman,* and *M. peltata*. Presence of strigillose hairs in the surface of *T. paniculata* leaves in its expanding phase which protect the leaves from herbivore damage (Palaniswamy and Bodnaryk, 1994; Kallarackal and Chandrasekhara 2007), and the probable presence of some anti feedants in the tender leaves about which data is non existing might be the factors limiting the feeding on tender leaves of *T. paniculata* leading to equal preference on its tender and senescent leaves.

Ranking and categorisation of host plants based on feeding preference:

Analysis of the feeding preference towards the leaves of common plants revealed that *H. brasiliensis* is the most preferred host plant for *L. tristis* in both tender and senescent leaf category. High leaf nutrient levels in tender leaves resulting from nutrient resorption in deciduous trees (Aerts, 1996; Wright and Westoby, 2003; Vergutz *et al*., 2012) and the high nutrient levels in both tender and senescent leaves arising from regular fertiliser treatment in rubber plantations (Sabu *et al*., 2013) are the reasons for high preference towards tender and senescent leaves of deciduous *H. brasiliensis*.

Equal preference for tender *A. heterophyllus* leaves in level with tender *H. brasiliensis* leaves and selection of its senescent leaves as the preferred leaf resource after senescent *H. brasiliensis* leaves indicates that *A. heterophyllus* is the next most important host plant for *L. tristis* after *H. brasiliensis* and its leaves would be as nutrient rich as that of *H. brasiliensis*. Since *A. heterophyllus* is a common tree in rubber and non-rubber agribelts, availability of nutrients from annual fertiliser treatment in agribelts and the nutrients available from the decomposition of its fallen fruits and seeds could be making its leaves nutrient rich.

Theobroma cacao, *P. pinnata*, *P. marsupium* and *G. sepium* are the moderately preferred host plants of *L. tristis* after the most preferred *H. brasiliensis* and *A. heterophyllus*. However, since *L. tristis* is a litter dwelling detritivorous beetle that feed and breed in litter, availability of fallen leaves to the starved post-dormancy beetles is an important factor in determining the host plant potential. As senescent leaves of the deciduous *P. pinnata* are least preferred by *L. tristis* and there is no record of premature leaf fall of *P. pinnata* that makes its tender leaves available to *L. tristis* in field conditions, *P. pinnata* is not considered as a potential host plant of the beetle. Similar to *P. pinnata*, lack of tender leaf fall in *P. marsupium* restricts its ability to support *L. tristis* in field conditions. However, moderate feeding on its senescent leaves and its status as a dominant tree in the deciduous forests of south India (Sundarapandian *et al*., 2005; Nanda *et al.,* 2011) and as a shade tree in the agribelts in the eastern slopes of the south Western Ghats considered as the source region of *L. tristis* (Sabu *et al.,* 2007) points to the possibility of senescent *P. marsupium* leaves being an important food for *L. tristis* in these regions. Among the various host plants, *T. cacao* is a major plantation crop in rubber and non-rubber belts, and *G. sepium* is the most common hedge plant in agribelts as its leaves are utilisable as fodder and green manure and its ability for fast growth. Periodical pruning of mature and tender shoots of *T. cacao* and pruning and application of mature leaves of *G. sepium* as green manure by the farmers (Sabu *et al*., 2012; Kwesiga *et al,*. 2003; Bah and Rahman, 2001) makes tender and senescent leaves of *T. cacao* and senescent leaves of *G. sepium* available to *L. tristis* in agribelts in addition to the regular leaf shedding in evergreen *T. cacao* and annual leaf fall in deciduous *G. sepium*. Regular fertilizer addition in *T. cacao* plantations that makes its leaves nutrient rich and makes *T. cacao* an important alternate host plant of *L. tristis* in rubber belts and a potential host plant in non rubber belts. Preference towards senescent leaves of *G. sepium* in level with senescent *H. brasiliensis* leaves, moderate feeding on its tender leaves after *H. brasiliensis*, *A. heterophyllus*, *T. cacao,* and *P. pinnata* and its prevalence in both rubber and non rubber belts makes *G. sepium* an important host plant of *L. tristis* in the region. Lower nutrient resorption from senescent leaves in N fixing plants that makes its senescent leaves nutrient rich (Killengback, 1993; Eckstein *et al*., 1999; Norris and Reich, 2009; Vergutz *et al*., 2012) could be the reason for high preference of *L. tristis* towards senescent leaves of *G. sepium*. Prolonged availability of senescent leaves of *G. sepium* from January to May, the period of deciduous leaf fall in *G. sepium* trees (Simons and Stewart, 1994), which is in perfect synchrony with active life stages of *L. tristis* (Sabu *et al*., 2008) altogether indicates that the less noticeable but common *G. sepium* to be an important host plant of *L. tristis* after *H. brasiliensis* in both rubber and non rubber belts.

Among the seven low preferred host plants, equal preference towards senescent and tender leaves of *T. paniculata* and *A. saman* and their

distributional pattern makes them more important host plants than the other five host plants for the following reasons. *Terminalia paniculata* is a common shade tree retained for green manure in the agribelts in the moist south Western Ghats and is a dominant tree in the natural forests of the Western Ghats (Sundarapandian *et al*., 2005; Nanda *et al*., 2011). Annual leaf fall of *T. paniculata* during pre-summer and widespread use of its senescent and tender leaves as green manure during summer lead to availability of its litter as food resource and breeding habitat for *L. tristis*. *Albizia saman* is another common evergreen tree across south India and is a shade tree in the campuses of many institutions and its fallen senescent leaves are available during all seasons. Though *T. indica* and *C. fistula* are common trees in south India and *A. hirsutus* common in rubber belts, low feeding on their senescent leaves and non availability of tender leaves by premature leaf fall makes them less important host plants of *L. tristis*. Despite the fact that with low consumption rates and preference towards tender leaves, the following aspects makes *M. indica* and *A. occidentale* as host plants of significance in south India. Wider presence of *M. indica* orchards in south India, its selections as a common shade tree in residential belts, occurrence of multiple leaf flushing (Bally, 2010) and the tender leaf fall due to wind action and leaf disease (personal observations) ensures regular availability of its tender leaves to *L. tristis* in rubber and non-rubber belts. Similarly preference towards tender *A. occidentale* leaves and presence of *A. occidentale* plantations with occasional premature leaf fall due to powdery mildew disease and defoliation by the caterpillar, *Nudaurelia bellina* (Orwa *et al*., 2009 d) leads to tender leaf availability to *L. tristis.*

Peltophorum pterocarpum, *S. mahagoni*, *M. peltate,* and *T. grandis* are the least preferred host plants. Low N and high phenol content of *S. mahagoni* and *T. grandis* leaves which provides resistance from insect herbivory (Basu *et al*., 2010) along with leaf toughness of *T. grandis* and leaf toughness and waxiness of *S. mahagoni* leaves could be the reasons for low feeding on these two plants. Low preference towards *S. mahagoni* and *T. grandis* indicates that litter stands of *S. mahagoni* or *T. grandis* monoculture plantations would not be selected by *L. tristis* as its breeding sites. Leaf toughness and waxiness of *P. pterocarpum* and leaf toughness of *M. peltata* could be the reason for low feeding on these plants and data on the chemical traits of these two plants are non existent. Low preference towards *P. pterocarpum* which is a common shade tree in the premises of most old buildings and *M. peltata*, a common shade tree, in the agriculture belts indicate that these two trees would not aid in the population build up of *L. tristis* in any region.

Major host plants of *L. tristis* are *H. brasiliensis*, *A. heterophyllus*, *T. cacao*, and *G. sepium* in moist regions and *P. marsupium*, *P. pinnata*, *T. indica*, *M. indica*, and *T. paniculata* in dry regions of south India. General bias towards tender leaves of most host plants is distinct. Host plants fall under three heads: tender leaf preferred, senescent leaf preferred, and both tender and senescent leaf preferred. *L. tristis* is a generalist feeder of most plants and hence scarcity of a few host plants may not regulate its population build up and possibility of its spread to non rubber belts is high. High preference of *L. tristis* towards senescent leaves of *G. sepium* and its easy availability makes *G. sepium* an important host plant of *L. tristis* in rubber and non rubber belts. Abundance of *L. tristis* in regions where less preferred host plants like *T. paniculata*, *M. indica,* and *A. occidentale* are abundant points towards the possibility of low ranked host plants supporting *L. tristis*. This necessitates data on the reproductive performance of *L. tristis* on both high and low preferred host plants to reach at conclusion. Lack of data on leaf chemical quality of the native plants makes even preliminary interpretation of leaf age class and host plant related variations in the feeding preference of *L. tristis* impossible.

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Odonata diversity in and around Vadodara, Gujarat, India

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ABSTRACT: Investigation on the diversity of Odonates revealed a total of 38 species belonging to two suborders, six families, and 24 genera in and around Vadodara, in Gujarat, which included 15 species of Zygoptera (damselfly) and 23 species of Anisoptera (dragonfly). Out of the 38 species, 10 species are new records for the Vadodara. Most number of species was found in water reservoirs as compared to urban ponds and area around Mahi River. Furthermore, it was observed that areas around the rivers were adversely affected because of nearby sand mining. Amongst damselflies and dragonflies the population of damselflies was richer. Renovation of Urban ponds leads to decrease in their diversity due to loss of vegetation indicating anthropogenic pressure on species diversity.
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KEY WORDS: Damselflies, dragonflies, conservation, reservoir, mine

INTRODUCTION

Dragonflies are amongst the most ancient of winged insects, dating back well into the Permian period (Grimaldi and Engel, 2005). Dolny and Asmera (1989) recognized them as good indicators of environmental change as the larvae and adult both are sensitive to habitat degradation and climate change. Diversity of the local Odonates fauna is determined by the overall ecological quality of water bodies and related land water ecotones (Chovanec *et al.,* 2004; Smith *et al.,* 2007). The eight super-families, 29 families and around 58 sub-families of Dragonflies for approximately 600 genera and 6000 named species have so far been described all over the world (Mitra, 2006). Odonate fauna of India is known by 3 sub-orders, 17 families, 139 genera and 499 species and subspecies (Subramanian, 2014). Very few studies have been carried out on the diversity of Odonates in Gujarat. ZSI scientists during general survey of Gujarat enlisted 48 species (Prasad, 2004). Other than that Rathod *et al.* (2016) and Rohmare *et al.* (2015) had worked in Gujarat and described 80 species of Odonates from Gujarat. While working on total insect diversity in different habitats of Vadodara, 22 species of Odonates were reported (Naidu, 2008). During the working on terrestrial birds and their prey 45 species of Odonates from Vadodara were reported but identified only 28 up to species level (Gandhi, 2012). Rohmare *et al. (*2015) working in Central Gujarat described 42 species having a place with 27 genera from 6 district including 28 species of 21 genera from Vadodara. Dragonflies and damselflies are amongst the prominent and colourful insects in tropical landscapes. In addition to providing aesthetic pleasure, studying them could give us valuable insights about ecosystem health, especially of

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wetlands. Therefore, for a better understanding of ecology, diversity, distribution and conservation the work on the diversity of Odonate was started from June 2017 with the study of Ordinates of various sites of Vadodara.

MATERIALS AND METHODS

Study Area: Vadodara is situated at 22.30°N 73.19°E in western India at a rise of 39 meters on the banks of the Vishwamitri waterway, southeast of Ahmedabad. An observation review in and around Vadodara was made for site choices. Distinct habitats of living spaces were chosen based on natural components, vegetation, encompassing condition and anthropogenic pressure, to get an insight of the best possible Odonate diversity

Timbi Irrigation Reservoir (TIR: Plate 1) is situated around 15 km east of the Vadodara city. The water of the reservoir is utilized for the local reason, for example, agriculture fields, washing the garments and utensils and cleaning up while the drier side of the supply is utilized as grazing field by cattle.

Ajwa Reservoir (AR: Plate 1) situated 25 km from the Vadodara city, the water of the store is used for the neighbourhood region, for instance, washing of clothing and utensils and tidying up while the drier side of the supply is used as grazing field for cattle.

Urban Pond sites (Plate 1) Under the smart city project a great deal of advancement is going on like, development of new infrastructure and residential complexes, beautification of ponds, sculpture park and boating close to ponds. This demonstrates a anthropogenic weight on the ponds which influences the natural habitat of the ponds.

Mahi River Sites (Plate 1) study was conducted at two different locations of Mahi River which are: A) Sindhrot Check dam which is a picnic and religious spot for the locals of Vadodara City which brings about tossing loads of waste in the streaming water; B) Angadh Village where sand mining on the banks of Mahi River is prone.

Sampling Method

Systematic survey method was followed in which the observation time was from 9am to 1pm. For observation visual encounter method was followed in transect. Point count method was used for counting individual number of species. Odonates present on both the sides of the water bodies were watched while walking on transect and recorded. Adult Odonates were collected from all the sites by using a standard insect net. Live dragonflies were collected in transparent container with a wide mouth plastic bottle and were utilized to store them alive. Collected specimens were killed by putting the jar in deep freeze for 10 minutes. The Odonates were taken out from the jar and entomological pins were passed through the thorax and settled on the spreading board. The wings were then spread in such a manner that the inner margin of the forewing remained perpendicular to the body of the insect. The collected specimens of Odonates comprised of both dragonfly and damselfly. They were identified with the help of suitable guides (Subramanian 2009; Nair 2011; Kiran and Raju, 2013) and (Fraser, 1936).

RESULTS

During the study period, 38 species belonging to 24 genera, under 6 families, and 2 suborders were recorded from four different sites in and around Vadodara. A total 15 species of Zygoptera and 23 species of Anisoptera were identified. The highest number of Odonate species (34) was recorded in Timbi irrigation reservoir (21 species of Anisoptera and 13 species of Zygoptera) followed by Ajwa reservoir with 32 species (19 species of Anisoptera and 13 species of Zygoptera). 27 Species were recorded near banks of Mahi River (15 species of Anisoptera and 12 species of Zygoptera) and least species (16) recorded from urban ponds (11 species of Anisoptera and 5 species of Zygoptera) (Table 1).

The highest number of Odonates recorded belonged to family Libellulidae with 21 species (Table 3) followed by family Coenagrionidae with 10 spceies (Table 2) and least number were from family Aeshnidae just with one species (Table 3). Family

Reed Beds at Ajwa Reservoir

Reed Beds at Timbi Irrigation Reservoir

Periphery of Urban Pond (Gotri Pond)

Construction around Urban Pond (Harni Pond)

Mining near the Riparian Zone (Angadh)

Riparian Zone of Mahi River (Sindhrot)

Plate 1. Study sites

Ischnura senegalensis (resting on a twig)

Pseudagrion hypermelas (resting on a leaf)

Pseudagrion rubriceps (Mating pair)

Lestes viridulus (resting)

Paragomphus lineatus (hovering)

Diplacodes nebulosa (hovering)

Plate 2. Species of Odonata collected from three different habitats.

Lestidae (Table 2) represented by three species, families Platycnemididae (Table 2) and Gomphidae (Table 3) were represented by two species each. Ten species i.e. *Agriocnemis pygmaea, Ceriagrion coromandelianum, Ischnura aurora, Ischnura senegalensis, Acisoma panorpoides, Brachythemis contaminata, Crocothemis servilia, Orthetrum sabina, Pantala flavescens*

Indothemiscarnatica (resting on a twig)

Orthetrum pruinosum (resting on a branch)

Tholymis tillarga (collected specimen)

Trithemis kirbyi (resting at rock)

Plate 3. Species of Odonata collected from three different habitats.

and *Trithemis aurora* were most common and widely distributed species as they were recorded from all sites (Table 2 and 3).

Fifteen species were recorded from at least three sites i.e. *Lestes thoracicus, Copera marginipes, Enallagma cyathigerum, Rhodoischnura nursei, Pseudagrion decorum, Pseudagrion hypermelas, Pseudagrion rubriceps, Anax guttatus, Bradinopyga geminata, Diplacodes trivialis, Neurothemis tullia, Orthetrum pruinosum, Tholymis tillarga, Trithemis Kirbyi* and *Trithemis pallidinervis* (Table 2 and 3).

Timbi irrigation reservoir and Ajwa reservoir have 32 species as common. *Paragomphus lineatus* and *Bradinopyga geminate* were the species which recorded from Timbi irrigation reservoir not from Ajwa reservoir and 8 species i.e. *Indothemis carnatica, Pseudagrion microcephalum, Ictinogomphus rapax, Brachydiplax sobrina, Diplacodes nebulosa, Orthetrum taeniolatum, Rhyothemis variegata* and *Trithemis festiva* were only recorded from these two sites and were absent from other sites (Table 2 and 3).

Although the habitat of both Timbi and Ajwa is almost similar in spite of that Timbi is slightly more diverse because of rocky substrate and also the construction of residential complexes near Timbi leads to a good roosting habitat for few urban species like *Bradinopyga geminate. Disparoneura quadrimaculata* and *Lestes umbrinu* species (Table 2) were only recorded

Table 1. Species richness of dragonflies and damselflies in and around Vadodara

Sr. No	Study Site	Dragonfly	Damselfly	Total
1	Timbi Irrigation Reservoir	21	13	34
2	Ajwa Reservoir	19	13	32
3	Mahi River	15	12	27
4	Urban ponds	11	5	16

Table 2. A comparison of damselflies collected from different sites in and around Vadodara

Taxon	Study Sites			
	Timbi	Ajwa	Mahi River	Urban Ponds
Suborder : Zygoptera				
Family: Lestidae				
Lestes thoracicus Laidlaw, 1920	Y	Y	Y	N
Lestes umbrinus Selys, 1891	N	N	Y	N
**Lestes viridulus* Rambur, 1842	Y	Y	N	N
Family:Coenagrionoidea				
Agriocnemis pygmaea (Rambur, 1842)	Y	Y	Y	Y
*Ceriagrion coromandelianum (*F. *1798)*	Y	Y	Y	Y
Enallagma cyathigerum (Charpentier 1840)	Y	Y	N	Y
Ischnura aurora (Brauer 1865)	Y	Y	Y	Y
**Ischnura senegalensis* (Rambur 1842)	Y	Y	Y	Y
Rhodischnura nursei (Morton, 1907)	Y	Y	Y	N
Pseudagrion decorum (Rambur1842)	Y	Y	Y	N
**Pseudagrion hypermelas* Selys,1876	Y	Y	Y	N
Pseudagrion microcephalum (Rambur1842)	Y	Y	N	N
**Pseudagrion rubriceps* Selys, 1876	Y	Y	Y	N
Family: Platycnemididae				
Copera marginipes (Rambur 1842)	Y	Y	Y	N
Disparoneura quadrimaculata (Rambur 1842)	N	N	Y	N

The Species marked with asterisk **(*)** are the first records from Vadodara City. **Y** denotes presence of Species and **N** denotes absence of species.

from the Mahi river site and *Diplacodes lefebvrii* species (Table 3) was absent at Timbi irrigation reservoir and Ajwa reservoir.

Generally, it is seen that flowing water bodies have more diversity but in the present study at two location of Mahi River the diversity was less. This could be because of anthropogenic pressure as the Sindhrot check dam is a tourist place and sand mining activities are very prevalent near Angadh village so disturbance level is high at this places. Due to mining activities near the Angadh village it leads to channelling of river water and temporary water puddles around the riparian area which acts as microhabitat for Damselflies. This could be the reason for good diversity of damselflies at the riverine site.

Least diversity is recorded at Urban Ponds because of the loss of vegetation surrounding the ponds.

Under smart city project beautification of pond is going on which leads to removal of vegetation and concretization of the pond periphery. This affects the diversity as no suitable roosting site is available. Therefore only 5 species of damselflies belonging from a single family were observed and 11 species of Dragonfly from 2 families was recorded.

After the present study ten species (Plate 2 and Plate 3) from in and around Vadodara are being reported for the first time. These are *Lestes viridulus* Rambur, 1842, *Ischnura senegalensis* (Rambur 1842), *Pseudagrion hypermelas* Selys, 1876 and *Pseudagrion rubriceps* Selys, 1876 (Table 2); *Paragomphus Lineatus* (Selys 1850), *Diplacodes nebulosa* (Fabricius 1793), *Indothemis carnatica* (Fabricius 1798), *Orthetrum pruinosum* (Burmeister, 1839), *Tholymis tillarga* (Fabricius 1798) and *Trithemis kirbyi* (Selys 1891) (Table 3).

Table 3. A comparison of dragonflies collected from different sites in and around Vadodara

Taxon	Study Sites			
	Timbi	Ajwa	Mahi River	Urban Ponds
Suborder : Anisoptera				
Family : Aeshnidae				
Anax guttatus (Burmeister 1839)	Y	Y	Y	N
Family: Gomphidae				
Ictinogomphus rapax (Rambur 1842)	Y	Y	N	N
**Paragomphus Lineatus* (Selys 1850)	N	Y	N	Y
Family : Libellulidae				
Acisoma panorpoides (Rambur 1842)	Y	Y	Y	Y
Brachydiplax sobrina (Rambur 1842)	Y	Y	N	N
Brachythemis contaminata (Fab 1793)	Y	Y	Y	Y
Bradinopyga geminate (Rambur 1842)	Y	N	Y	Y
Crocothemis servilia (Drury 1770)	Y	Y	Y	Y
Diplacodes lefebvrii (Rambur 1842)	N	N	Y	Y
**Diplacodes nebulosa* (Fabricius 1793)	Y	Y	N	N
Diplacodes trivialis (Rambur 1842)	Y	Y	N	Y
**Indothemis carnatica* (Fab 1798)	Y	Y	N	N
Neurothemis tullia (Drury 1773)	Y	Y	Y	N
**Orthetrum pruinosum* (Burmeister,1839)	Y	Y	Y	N
Orthetrum sabina (Drury 1770)	Y	Y	Y	Y
Orthetrum taeniolatum (Schneider 1845)	Y	Y	N	N
Pantala flavescens (Fabricius 1798)	Y	Y	Y	Y
Rhyothemis variegata (Linnaeus 1763)	Y	Y	N	N
**Tholymis tillarga* (Fabricius 1798)	Y	N	Y	Y
Trithemis aurora (Burmeister 1839)	Y	Y	Y	Y
Trithemis festiva (Rambur *1842)*	Y	Y	Y	N
**Trithemis kirbyi* (Selys 1891)	Y	Y	N	N
Trithemis pallidinervis (Kirby 1889)	Y	Y	Y	N

The Species marked with asterisk (*) are first records for Vadodara City. Y denotes presence of Species and N denotes absence of species

DISCUSSION

Wetlands are among the most impacted habitat because of land conversion (Reece and McIntyre, 2009) and their important biological resources can easily be lost through clearance and overuse (Clausnitzer, 2004). Wetlands are one of the major ecosystems that support the Odonate density and diversity. Hence to save Odonate species wetlands need to be conserved. Recent studies around the world have suggested that Odonates respond to anthropogenic pressures and thus may serve as useful indicators of habitat quality in terms of species occurrence and diversity (Sahlen, 2006; Suhling *et al.,* 2006).

Presence of reed beds at Timbi Irrigation Reservoir and Ajwa Reservoir is one of the most important factor behind the high diversity as reed beds are a type of grass which grows up to 4-6 feet and remain submerged in water throughout the year , as water from Narmada canal is present throughout the year so it acts as a perfect habitat for Odonates.

Along with reed beds Ipomoeas, Water lily, Hydrilla, Water hyacinth, Calotropis, Prosopis, were the major plants presents which Odonates uses for perching, resting and most importantly for egg laying.

During the present study Club tails were more abundant on the water reservoir whereas they were less on the riverine ecosystem (Subramanian, 2009) while working on ecology of Dragonfly in Western Ghats indicate that Club tail, Bamboo tail, Reed tails, Torrent hawk, Torrent darts are good indicators of health of riverine ecosystem. The investigation shows that Libellulids were most predominant on Mahi River and Urban ponds while Gomphids were in great number at Irrigation reservoirs. Presence of generalist Libellulids, particular species like *Brachythemis contaminate* clearly shows deteriorating habitats and contamination of water. The findings suggest that the diversity of Vadodara is quite good but there are many threats to Odonates of Vadodara like over construction and overcrowding by the birdwatchers near Timbi Irrigation Reservoir, even the release of water from Narmada River to reservoir all of a sudden increases water level of the Reservoir and many anthropogenic activities like washing of clothes, utensils and grazing cattle around the reservoir also destruct the habitat.

Though riverine ecosystem have more diversity but our study reports that Mahi River has less diversity due to anthropogenic activities like picnic place near the riparian area, throwing of religious stuffs, garbage, plastic waste, burning of waste products etc. All this leads to the pollution at the riverine ecosystem. On the other side of Mahi River sand mining is prevalent which leads to fragmentation of habitats thus an overall decrease of the diversity even common species of riverine ecosystem like Club tails were very rarely observed.

Under the smart city project, beautification of ponds, development of Sculpture Park and renovation of gardens around the ponds is going on which leads to the removal of the vegetation in and around the ponds and the periphery of ponds being replaced by concrete. This disturbs the normal habitat of Odonates resulting in low population at urban ponds as only 16 species from 3 families which are very common and most adaptive species and even the individuals were very less. One of the biggest threats to Odonata is an unplanned urban development as it directly leads to the destruction of their habitat. To save the extinction of several Odonate species wetlands need to be conserved. Recent studies around the world have suggested that Odonates respond to anthropogenic pressures and thus may serve as useful indicators of habitat quality in terms of species occurrence and diversity (Sahlen, 2006; Suhling *et al.,* 2006). Conservation strategy needs to be developed and implemented to stop further deterioration of the Odonate species.

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Seasonality of butterflies in Alagar Hills reserve forest, India

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ABSTRACT: Seasonal prevalence of butterflies carried out in Alagar hills reserve revealed more number of butterflies in the summer with higher density of Nymphalid butterflies followed by Papilionidae. Hesperiidae species were more in post monsoon season than in rainy or dry season. On comparing the prevalence of butterflies with environmental factors, Hesperiidae exhibited a positive correlation with rainfall, humidity and negative correlation with temperature whereas Nymphalidae and Papilionidae showed a positive correlation with temperature and negative correlation with humidity. Study showed that summer period is a suitable period for butterfly prevalence in Alagar Hills. © 2020 Association for Advancement of Entomology

KEY WORDS: Alagar Hills, Nymphalidae, summer season

INTRODUCTION

With the scenario of recent global warming, evidence documents ongoing changes in distribution of terrestrial species throughout the earth (Parmesan and Yohe, 2003). Seasonality is not a strange phenomenon in insect population (Hussain *et al*., 2011). Their population dynamics is influenced by a variety of factors (Rajagopal *et al*., 2011). Understanding the relationship between seasonality and geographical distribution of individual species is important for predicting anthropogenic forest disturbances (Wright *et al*., 1993). Some species show fluctuation in relation to variation in rainfall and host plant dynamics (Hill *et al*., 2003). Global warming has affected distribution ranges of many butterfly species (Hoyle and James, 2005). Abiotic factors like temperature, humidity and solar radiation have profound activity on the insects like butterflies because of their reduced thermal inertia (Piexoto and Beason, 2009). Most butterflies respond to habitat and climate change (Feest *et al*., 2011). Butterflies are sensitive to environmental gradient in tropical regions particularly in areas with well-defined wet and dry seasons. Many satyrine butterfly species of tropical low lands are known to be sensitive to changes in humidity (Braby, 1995). Phenological pattern in butterflies may be determined by fruiting and flowering plants (Scott, 1986), annual humidity distribution (Wolda, 1989), photoperiodic changes (Shapiro, 1975), substrate availability and palatability of larval food plants (Owen *et al*., 1972).Global warming has affected distribution ranges of many butterfly species and has led to the extinction or endangerment of others (Hoyle and James, 2005).

MATERIALS AND METHODS

The present study area Alagar hills reserve forest 10° 5' 30"N to 10° 9' 40"N and 78° 10' 20"E to 78°17'7"E of the Eastern Ghats and it is situated in

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the Nattam Taluk of Dindigul of Tamil Nadu, India. The prevalence of butterflies during the four different seasons namely, monsoon, pre monsoon, post monsoon and summer season was analyzed using standard transect sampling method (Ishii, 1993). The survey of butterflies was carried out at eight sites for two years from November2009 to October 2011. The butterflies were sampled using line transect method count (Pollard and Yates 1993).Collection of specimen was avoided in most cases and butterflies were documented using Canon and Nikon cameras with appropriate high quality lenses. Butterflies were identified with the help of various field guides (Kunte, 2000; Antram, 2002; Sharmila and Thatheyus, 2014).To investigate the seasonal abundance of tropical butterfly species; it is important to examine the climate data pertaining to rainfall, temperature and humidity (Thakur and Ghosh, 2014). The records of the mean daily temperature, mean daily humidity and total rainfall obtained for the period November 2009 to October 2011 were collected to find out the monthly average. The three ecological parameters namely rainfall, temperature and humidity were correlated with familial prevalence of butterflies using Karl Pearson's coefficient of correlation.

RESULTS AND DISCUSSION

Alagar Hills reserve forest registered more number of butterflies in the S4 season (summer) with higher density of Nymphalid butterflies in both the years, followed by Papilionidae. Nymphalidae exhibited sudden spurt and increase in the summer season compared to other seasons in both the years while the density of Papilionids did not show such spurts in various seasons. The total number of butterflies was highest in the first year during summer season with 51,788 and in the second year it was 30,909. In both the years of study, summer season had the maximum population. But the total population showed a decreasing trend in the second year (Fig.1). However irrespective of butterflies representing different families butterfly prevalence was the highest in summer season.

Among Nymphalids noted in Alagar Hills reserve forest, many species were seen in all the seasons, but certain species were prevalent only in a single season. Among the prevalent thirty two species seventeen species were found in all the seasons (Table 1). Most of the Papilionids were seen in all the seasons (Table 2). Among Pierids, forty percent species were seen in all the four seasons, and most of the abundant species were seen in all the seasons (Table 3). In Lycaenidae about sixteen percent were seen in all the seasons (Table 4). None of the Hesperiids were seen in all the seasons (Table 5). On comparing with the prevalence of butterflies of different families with the amount of rainfall, temperature and humidity, a few families showed correlation with these environmental factors. Hesperiidae exhibited a positive correlation with rainfall. Nymphalidae and Papilionidae showed a positive correlation with temperature, whereas Hesperiidae exhibited negative correlation with temperature. Nymphalidae and Papilionidae showed negative correlation with humidity while Hesperiidae exhibited positive correlation with humidity (Table 6).

Seasonality is a common phenomenon in insect population (Wolda, 1989). Butterflies are neither identical nor abundant throughout the year and their numbers decline over a period owing to harsh climatic changes and anthropological activities. Their appearance in the same place fluctuates with seasonal change and butterfly ranges are affected by global climate change (Forister *et al*., 2009). Hesperiids showed higher prevalence in post monsoon season during January, February and March and they differed in their phenological behaviour compared to other families. Similar results were also observed by Pozo *et al*. (2008) where they observed Hesperiidae species richness being more in post monsoon season than that of rainy or dry season.

Many of the Nymphalids found in Alagar Hills reserve forest were seen in all seasons. These Nymphalid larvae should be able to feed on wide range of locally available plant species and may face fewer constraints on their prevalence throughout the year rather than monophagous species. The species with wide range of host plants showed low seasonality. Similar type of results was

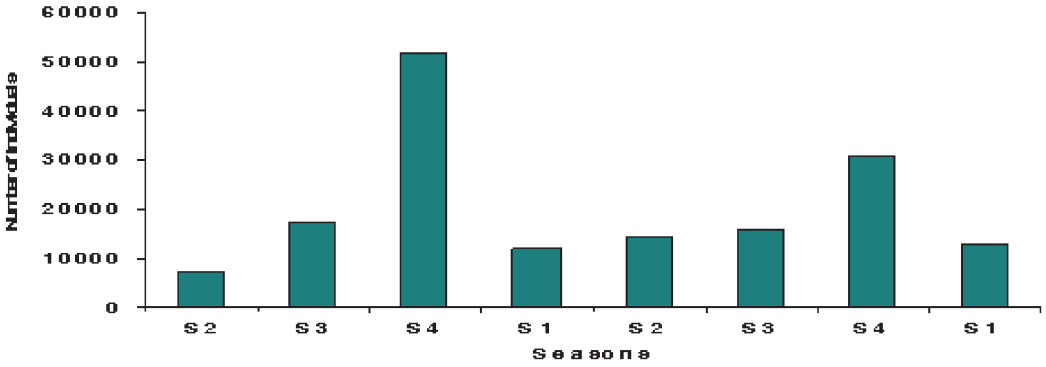

Fig 1. Butterfly sighting in different seasons during the study period

Table 1. Nymphalids in different seasons in Alagar Hills reserve forest

Sl.No.	Species	Seasons							
		S2	S3	S4	S1	S2	S3	S4	S1
1	*Acraea violae*(Fabricius)	+	+	+	+	+	+	+	+
2	*Ariadne ariadne*(Linnaeus}	+	+	+	+	+	+	+	+
3	*Charaxes solon* (Fabricius)	+	+	+	+	+	+	+	+
4	*Danaus chrysippus*(Linnaeus)	+	+	+	+	+	+	+	+
5	*Danaus genutia*(Cramer)	+	-	-	-	+	+	+	+
6	*Euploea core* (Cramer)	+	+	+	+	+	+	+	+
7	*Euploea midamus*(Linnaeus)	-	-	-	-	-	+	-	-
8	*Euthalia aconthea*(Cramer)	+	+	-	+	+	+	+	-
9	*Euthalia nais*(Forster)	+	-	-	-	-	-	-	-
10	*Hypolimnas bolina*(Linnaeus)	-	-	-	-	-	+	+	+
11	*Hypolimnas misippus*(Linnaeus)	+	+	+	+	+	+	+	+
12	*Junonia almana*(Linnaeus)	-	-	-	-	-	+	-	-
13	*Junonia atlites*(Linnaeus)	-	-	-	-	-	-	+	-
14	*Junonia hierta*(Fabricius)	+	+	+	+	+	+	+	+
15	*Junonia iphita*(Cramer)	+	+	-	+	-	-	-	-
16	*Junonia lemonias*(Linnaeus)	+	+	+	+	+	+	+	+
17	*Junonia orithiya*(Linnaeus)	+	+	+	+	+	+	+	+
18	*Libythea lepita*(Godrat)	+	+	+	+	+	+	+	+
19	*Melanitis leda*(Linnaeus)	+	+	+	+	+	+	+	+
20	*Moduza procris*(Cramer)	-	-	-	-	-	+	-	-
21	*Mycalesis patnia*(Moore)	+	+	-	+	+	+	+	+
22	*Mycalesis visala*(Moore)	-	-	-	-	-	+	+	+
23	*Neptis ananta*(Moore)	-	+	-	-	-	-	-	-
24	*Neptis hordonia*(Stoll)	+	+	+	+	+	+	+	+
25	*Neptis hylas*(Linnaeus)	+	+	+	+	+	+	+	+
26	*Phalanta phalantha*(Drury)	+	+	+	+	+	+	+	+
27	*Polyura athamas*(Drury)	+	+	+	+	+	+	+	+
28	*Thaumantis diores*(Doubleday)	-	-	-	-	-	+	-	-
29	*Tirumala septentrionis*(Butler)	+	+	+	+	+	+	+	+
30	*Ypthima baldus*(Fabricius)	-	-	-	-	-	+	-	-
31	*Ypthima ceylonica*(Hewitson)	+	+	+	+	+	+	+	+
32	*Ypthima huebneri*(Kirby)	+	+	-	+	+	+	+	+

+ present - absent

Table 2. Papilionids in different seasons in Alagar Hills reserve forest

Sl.No.	Species	Seasons							
		S2	S3	S4	S1	S2	S3	S4	S1
1	*Atrophaneura aristolochiae* (Fabricius)	+	+	+	+	+	+	+	+
2	*Atrophaneura hector* (Linnaeus)	+	+	+	+	+	+	+	+
3	*Graphium agamemnon*(Linnaeus)	+	+	+	+	+	+	+	+
4	*Graphium cloanthus*(Westwood)	+	+	+	+	+	+	+	+
5	*Graphium doson*(C&R Felder)	+	+	+	+	+	+	+	+
6	*Graphium nomius*(Esper)	+	-	+	+	+	+	+	+
7	*Graphium sarpedon*(Linnaeus)	-	-	-	-	-	+	+	+
8	*Papilio crino*(Fabricius)	+	+	+	-	+	+	-	-
9	*Papilio demoleus*(Linnaeus)	-	-	-	-	-	+	-	-
10	*Papilio polymnestor*(Cramer)	+	+	+	+	+	+	+	+
11	*Papilio polytes*(Linnaeus)	+	+	+	+	+	+	+	+
12	*Troides minos*(Cramer)	+	+	+	+	+	-	-	-

+ present - absent

Table 3. Pierids in different seasons in Alagar Hills reserve forest

Sl.No.	Species	Seasons							
		S2	S3	S4	S1	S2	S3	S4	S1
1	*Appias albina*(Bosiduval)	+	+	+	+	+	+	+	+
2	*Appias libythea*(Fabricius)	-	-	+	-	-	+	+	+
3	*Appias lyncida*(Cramer)	-	+	+	+	+	+	+	+
4	*Belonis aurota*(Fabricius)	-	-	-	-	-	+	-	-
5	*Catopsila crocale*(Fabricius)	+	+	+	+	+	+	+	+
6	*Catopsila pyranthe*(Linnaeus)	+	+	+	+	+	+	+	+
7	*Cepora nerissa*(Fabricius)	+	+	+	+	+	+	+	+
8	*Ceprora nadina*(Lucas)	-	-	-	-	-	+	+	+
9	*Colotis amata*(Fabricius)	-	+	-	+	+	-	-	-
10	*Colotis danae*(Fabricius)	-	-	-	-	+	+	+	-
11	*Colotis fausta*(Oliver)	-	-	-	-	+	+	+	+
12	*Colotis vestalis*(Butler)	-	-	-	-	-	+	+	-
13	*Delias eucharis* (Drury)	+	+	-	-	+	+	-	-
14	*Eurema andersoni*(Moore)	-	-	-	-	-	+	-	-
15	*Eurema blanda*(Bosiduval)	-	-	-	-	-	+	+	+
16	*Eurema brigit*(Cramer)	+	+	+	+	+	+	-	-
17	*Eurema hecabe*(Linnaeus)	+	+	+	+	+	+	+	+
18	*Hebomia glauccippe*(Linnaeus)	+	+	+	+	+	+	+	+
19	*Ixias marianne*(Cramer)	+	+	+	+	+	+	+	+
20	*Ixias pyrene*(Linnaeus)	+	+	+	+	+	+	+	+
21	*Leptosia nina*(Fabricius)	+	+	+	+	+	+	+	+
22	*Pareronia ceylanica*(C&R Felder)	-	-	+	+	+	+	+	+
23	*Pareronia valeria*(Cramer)	+	+	+	+	+	+	+	+

+ present - absent

Table 4. Lycaenids in different seasons in Alagar Hills reserve forest

Sl.No.	Species	Seasons							
		S2	S3	S4	S1	S2	S3	S4	S1
1	*Abisara echerius*(Stoll)	-	+	-	+	+	-	+	+
2	*Anthene lycaenina*(C & R Felder)	-	-	-	-	-	+	-	-
3	*Arhopala pseudocentaurus* (Doubleday)	-	-	-	-	-	-	-	+
4	*Azanus jesous*(Guerin Meneville)	-	-	-	-	-	-	-	+
5	*Caleta elna*(Hewitson)	-	-	-	-	-	-	+	+
6	*Castalius rosimon*(Fabricius)	+	+	+	+	+	+	+	+
7	*Catochrysops strabo*(Fabricius)	-	-	-	-	-	-	+	+
8	*Chilades lajus*(Stoll)	+	+	-	-	-	+	+	+
9	*Curetis thetis*(Drury)	+	-	-	+	+	+	+	-
10	*Deuodrix perse*(Hewitson)	+	-	-	-	-	-	-	-
11	*Discolampa ethion*(Westwood)	-	-	-	-	-	+	+	-
12	*Jamides celeno*(Cramer)	-	-	-	-	-	+	-	-
13	*Leptotes plinius*Fabricius	-	-	+	-	-	+	-	-
14	*Megisba malaya*(Horsfield)	-	-	-	-	+	-	-	-
15	*Nacaduba berenice* (wood – Mason & de Niceville)	-	-	+	+	-	+	-	+
16	*Nacaduba kurava*(Moore)	-	-	-	-	-	+	+	-
17	*Prosotas dubiosa*(Evans)	+	+	+	+	+	+	+	+
18	*Prosotas felderi*(Murray)	+	+	+	+	-	+	+	-
19	*Pseudozizeeria maha*(Kollar)	-	+	-	+	+	-	+	+
20	*Rathinda amor* (Fabricius)	+	+	+	+	+	+	+	+
21	*Spindasis lohita(*Horsfield)	-	-	-	-	-	-	-	+
22	*Spindasis vulcanus*(Fabricius)	-	-	-	-	-	-	-	-
23	*Talicada nyseus*(Guerin Meneville)	+	+	+	-	+	+	+	+
24	*Tarucus nara*(Kollar)	+	+	+	+	+	+	+	+
25	*Zizina otis*(Fabricius)	+	+	+	+	+	+	+	+

+ present - absent

Table 5. Hesperiids in different seasons in Alagar Hills reserve forest

Sl.No.	Species	Seasons							
		S2	S3	S4	S1	S2	S3	S4	S1
1	*Caprona agama* (Moore)	-	-	-	-	-	+	-	-
2	*Caprona ransonnetti*(C & R Felder)	+	+	-	+	+	-	+	-
3	*Hasora chromus*(Cramer)	-	+	-	+	+	-	+	+
4	*Hasora taminatus*(Hubner)	-	-	-	-	-	-	+	-
5	*Lambrix salsala*(Moore)	-	-	-	+	+	-	-	-
6	*Tagiades japetus*(Stoll)	-	-	-	-	+	+	-	-
7	*Telicota ancilla*(Herrich-Schaffer)	-	-	-	-	-	+	-	-
8	*Telicota colon* (Fabricius)	-	-	-	-	+	+	+	-
9	*Thoressa astigmata*(Swinhoe)	-	-	-	-	-	+	-	-

+ present - absent

Table 6. Pearson correlation coefficient between Families and Environmental variables in Alagar Hills reserve forest

Variables	Correlation coefficient	Significance(5% level)
Papilionidae		
Rainfall	-0.1909	Insignificant
Temperature	0.6057*	Significant
Humidity	-0.3707*	Significant
Nymphalidae		
Rainfall	-0.1497	Insignificant
Temperature	0.5178*	Significant
Humidity	-0.3403*	Significant
Pieridae		
Rainfall	-0.1803	Insignificant
Temperature	0.2952*	Significant
Humidity	-0.1701	Insignificant
Lycaenidae		
Rainfall	0.0669	Insignificant
Temperature	0.1025	Insignificant
Humidity	0.0329	Insignificant
Hesperiidae		
Rainfall	0.3065*	Significant
Temperature	-0.3176*	Significant
Humidity	-0.3403*	Significant

explained by Hill *et al*. (2001). Certain species of butterflies of Alagar Hills reserve forest were found only in specific seasons and these species may belong to closed canopy forest. Baura *et al*. (2010) also suggested that butterfly abundance was influenced by humidity and rainfall. Photoperiod will increase as summer heat approaches and decrease towards the cold winter. Hill *et al*. (2001) also attributed the following reasons for the prevalence of certain species found in specific seasons, where few species may not be able to adapt to change in moisture availability and humidity. When there is change in canopy cover, there is change in the amount of light penetration, thus changing the microclimatic effect. This will have an impact on adult and larva and indirectly on plant quality. The reasons explained by Hill *et al*. (2001) can account for the prevalence of certain species of butterflies in few seasons in Alagar Hills reserve forest.

In the summer season S4 (April, May, June) highest number of Nymphalids were found in both the years of study. These results coincided with that of Baskar and Rahman (2003) where butterflies of families Papilionidae and Nymphalidae were abundant during March to May. Flight periods of open forest species reached their peak in summer months and during late monsoon (Kunte, 1997). The open forest species are sun loving species and they predominate, but when the area becomes too hot the individuals tend to reach cooler areas. The prevalence of Nymphalidae and Papilonidae during dry seasons might be due to their ability to maintain water balance as they are large size individuals as suggested by Janzen and Schoener (1987).

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Effect of coriander plant extract on the parasitization behaviour of *Trichogramma chilonis* Ishii (Hymenoptera : Trichogrammatidae)

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ABSTRACT: In the present investigation the coriander plant volatiles for the tritrophic interactions on the egg parasitoid *Trichogramma chilonis* Ishii is evaluated. The GCMS profile study of the foliage extract of coriander in both hexane and dichloromethane showed presence of 2-Dodecenal-(E), (E)-Tetradec-2-enal, Octadecane, Nonacosane, Hexadecane, Pentadecane and Heneicosane, which are of biologically active fractions in insects. In laboratory study the maximum parasitization was recorded in hexane extract treated *Corcyra* card (31.04 eggs/ card) compared to 28.16 eggs per card observed in untreated control. The data gathered on number of parasitized eggs hatched into adult indicated that in hexane extract treated *Corcyra* card had 91.19 per cent while parasitoid emergence was 29.30 eggs per card followed by 87.76 per cent in untreated control 24.90 eggs per card. The GCMS profile study of the foliage extract of coriander in both hexane and dichloromethane showed presence of 2-Dodecenal-(E), (E)-Tetradec-2-enal, Octadecane, Nonacosane, Hexadecane, Pentadecane and Heneicosane, which are of biologically active fractions in insects. The above findings reveal the possible role of such active chemicals in parasitoid compatibility of the intercrop. © 2020 Association for Advancement of Entomology

KEYWORDS: Coriander, *Trichogramma chilonis,* tritrophic interactions, *Corcyra*, GC-MS

INTRODUCTION

The augmentatory biocontrol agent *Trichogramma chilonis* Ishii egg parasitoid is widely used for the management of various lepidopteran pests including brinjal shoot and fruit borer *Leucinodes orbonalis* Guenee. There are reports that the periodical release of *T. chilonis*, the egg parasitoid effectively control *L. orbonalis* problem in brinjal cultivation with substan-tial increase in yield (Satpathy *et al.*, 2005). Sasikala *et al.* (1999) found that the egg parasitoid *T. japonicum* could efficiently reduce *L. orbonalis* damage in brinjal. Niranjana (2015) indicated the egg parasitoid *T. pretiosum* is efficient in brinjal ecosystem among different *Trichogramma* spp tested. However, information on the performance of *T. chilonis* in coriander intercropped brinjal crop is not available so the present study was carried out. This research has been carried out in Agricultural College and Research Institute, Killikulam in Thoothukudi district of Tamil Nadu.

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MATERIALS AND METHODS

Studies on coriander plant extract in influencing parasitization behaviour of T. chilonis:

The kairomone extract of coriander (Var. CO1) was obtained using different solvents *viz.*, Hexane, Dichloromethane, Acetone and distilled water. The coriander leaf sample (50 gm) was taken and macerated with the 50 ml of specific solvents using the pestle and mortar. The extract was filtered through glass funnel with filter paper (Whatman No. 42). A total volume of 100 ml of filtrate form each solvent was collected in a reagent bottle (250 ml). The solvent extracts were further concentrated to dryness using rotary evaporator (IKA RV10). The extract thus obtained using different solvent system was stored in air tight glass vials at -20^0 C for further use.

Studies on the volatile profile of coriander solvent extracts:

In an attempt to understand the volatile profile of the coriander leaf extracts of different solvents system, GC-MS technique (Bandoni *et al.,* 1998) was followed. Gas Chromatography–Mass Spectrometry (Shimadzu QP 2020) available in Centre of Innovation at Department of Biotechnology at Agricultural College and Research Institute, Madurai was used. The compounds were identified by comparing with the NIST spectral library.

The details on the instrumentation condition is as follow

Column type and Length	:	R_{xi} 5 MS Silica and 30m
Column diameter and Thickness	:	0.25mm and 0.25µm
Carrier gas	:	Helium
Flow rate	:	1 ml/ min
Injected port temperature	:	250^{0}C
Injection volume	:	0.5 µl
Split mode ratio	:	1:10
MS interface temperature	:	270^{0}C
MS ion sources temperature	:	200^{0}C
Oven temperature	:	70^{0}C with increase of 5^0 C per min to 120^{0}C ending with a 5 min isothermal at 280^0 C
Detector	:	MS
Total run time	:	40.00 min

Influence of coriander crop on parasitization behaviour of T. chilonis under laboratory condition (Free choice test):

Influence of coriander extract as kairomone on parasitization behaviour of *T. chilonis* was studied at a concentration of 0.1 per cent in respect of different solvent system. For this purpose the 0.1g of kairomone extract was dissolved in equal quantity of alcohol and the volume was made to 100 ml by using distilled water. The egg card of size 7cm × 2 cm having unparasitized *Corcyra* egg was taken and dipped into the kairomone extracts and shade dried. After shade drying the cards were labelled and hanged randomly from top of oviposition cage (45cm×35cm). For each treatment three cards were used. The cage had fine mesh (0.2 mm) fixed in all six side. The *T. chilonis* parasitized *Corcyra* card (0.5 cc) was placed inside the cage on a petriplate. The experimental setup was placed undisturbed in well ventilated dark place in the insect culture room maintained at 23-24^{0}C room temperature and 80 per cent RH. Four days of exposure period, the *Corcyra* cards were collected treatment wise and observed for the number of parasitized eggs which was easily differentiated by their black color. The cards were kept in laboratory undisturbed in a labelled zip lock cover for making further observations on extend of parasitization and parasitoid emergence pattern. Experiment was replicated thrice and repeated four times.

RESULTS AND DISCUSSION

Investigation on kairomone profile of coriander extracts (GC-MS study):

The performance of *T. chilonis* due to the influence of semiochemicals if any present in coriander was further investigated through biochemical analysis of volatile profile through GCMS study (Table 1). The GCMS profile of the foliage extract of coriander

Sample Information

Sample Described by customer as: Corander DCM

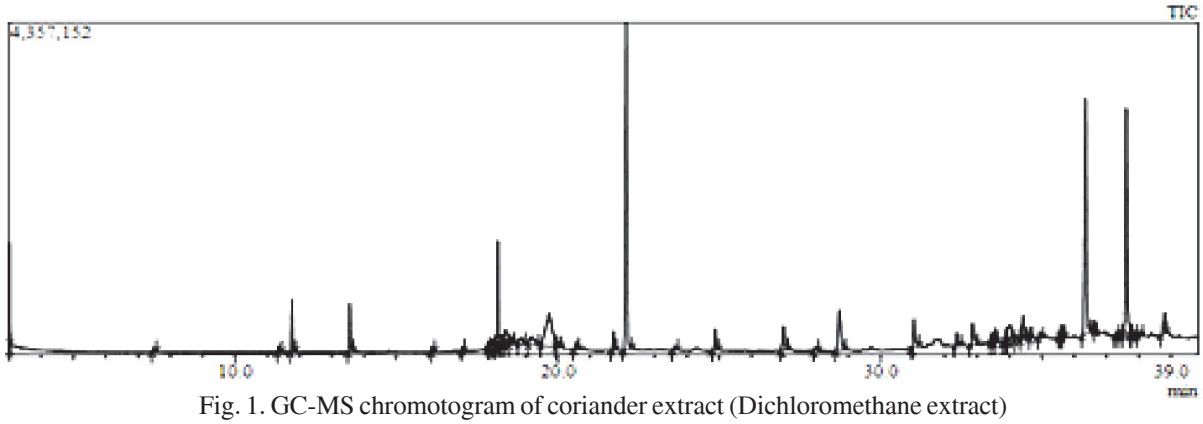

Fig. 1. GC-MS chromotogram of coriander extract (Dichloromethane extract)

Sample Information

Sample Described by customer as: Consider plant Hexane

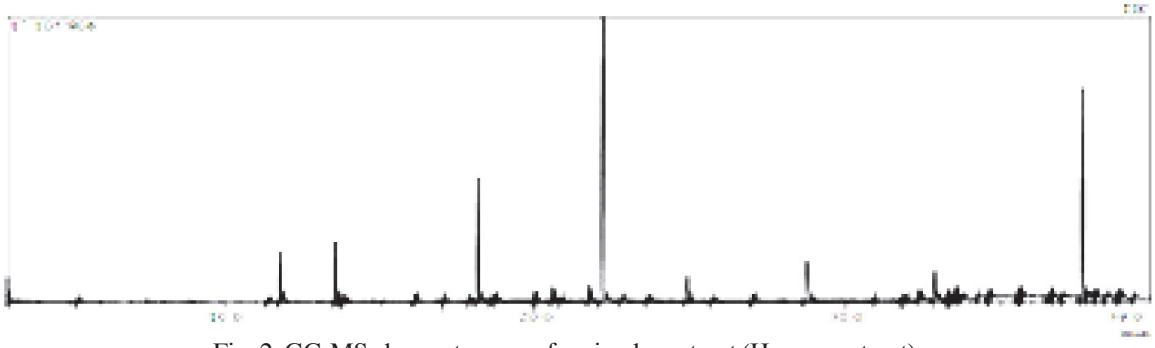

Fig. 2. GC-MS chromotogram of coriander extract (Hexane extract)

Table 1.The major volatile compounds identified from coriander plant extract using GC-MS

1. Hexane extract

S.No	RT	% Area	Chemical Compound
1.	11.791	4.92	Decanal
2.	13.733	3.39	2-Decen-1-ol, (E)-
3.	18.167	12.17	2-Dodecenal, (E)-
4.	22.179	27.88	(E)-Tetradec-2-enal
5.	28.763	4.01	(E)-Hexadec-2-enal
6.	37.633	20.62	n-Tetracosanol-1

2. Dichloromethane extract

S.No	RT	% Area	Chemical Compound
1.	11.769	2.74	Decanal
2.	13.554	2.39	2-Decenal, (Z)-
3.	18.147	4.57	2-Dodecenal, (E)-
4.	19.736	7.51	1-Heptacosanol
5.	22.117	18.66	(E)-Tetradec-2-enal
6.	27.001	2.00	Neophytadiene
7.	28.723	4.15	(E)-Hexadec-2-enal
8.	31.034	2.07	n-Hexadecanoic acid
9.	34.010	2.16	Octatriacontyltrifluoroacetate
10.	36.354	15.63	1-Triacontanol
11.	37.607	11.92	n-Tetracosanol-1
12.	38.804	1.59	Nonacosane

was studied in two different solvent systems namely hexane (non-polar) and dichloromethane (intermediately polar). The major compound recovered in the non-polar solvent system includes (E)-Tetradec-2-enal (27.88 %), n-Tetracosanol-1(20.62 %) and 2-Dodecenal, (E) (12.17 %). The other compounds found in significant proportion are decanal (4.92 %), 2-decenal, (Z) (3.39 %), and (E)-hexadec-2-enal (4.01 %) (Fig. 1).

The intermediate polar compound dichloromethane, the major volatile compounds detected includes (E)-Tetradec-2-enal (18.66 %), 1-Triacontanol (15.63 %), n-Tetracosanol-1 (11.92 %) and 2-Dodecenal, (E) (4.57 %) (Fig. 2). The other compounds found are decanal (2.74 %), 2-decenal, (Z) (2.39 %), and (E)-hexadec-2-enal (4.15 %). Among various compound detected 2-Dodecenal-(E),(E)-Tetradec-2-enal, Octadecane, Nonacosane, Hexadecane, Pentadecane and Heneicosane are of known biologically active fractions on insects. The major compound (E)-Tetradec-2-enal was found to an extend of 28.86 per cent in hexane and 18.66 per cent in dichloromethane. The other compound 2-Dodecenal-(E) was found upto 3.39 per cent in hexane and 2.39 per cent in dichloromethane. In hexane fraction the other bioactive compound identified includes Hexadecane (1.43 %), Pentadecane (0.76 %) and Octadecane (0.16 %). Nonacosane (1.59 %) and Heneicosane (0.38 %) are the two bioactive compounds recovered in dichloromethane fraction.

The present study is in accordance with Hilker *et al.* (2002) who found that the volatile semiochemicals, non-volatile cues also mediate host searching behaviour of *Trichogramma* spp. Plants on which adult moths have been present may provide such cues for host location. In the work of Bruce (2001), Tandon and Bakthavatsalam (2005) and Nathan (2007) they indicated that the host plant volatile components are known to influence the performance of biocontrol agent. Benzaldehyde, (S)-(±)-limonene, (R,S)-(±)-linalool, (E) myroxide, (Z)-b-Ocimene, phenyl acetaldehyde, and (R)- (±)-piperitone are components identified in *Tagetes erecta* that attract both *Helicoverpa armigera* and its parasitoids. They also reported the trap crop *T. erecta* is *Trichogramma*-friendly. Seni and Dilawari (2011) observed synomonal response of *H. armigera* females to flower extracts of African marigold, cotton, okra and pumpkin to varying degree which was due to the presence of favourable hydrocarbons.

Table2. Influence of coriander extracts on parasitization behaviour of *T. chilonis* (Free choice test)

Treatments	Number of parasitized eggs/ card (Mean of 20 observation)				Mean
	Exp 1	Exp 2	Exp 3	Exp 4	
Hexane extract of coriander	37.55(6.15)	29.00(5.37)	34.65(5.93)	26.75(5.22)	31.04
Dichloro methane extract of coriander	21.50(4.64)	18.21(4.25)	20.46(4.58)	14.55(3.85)	18.68
Acetone extract of coriander	23.71(4.91)	22.06(4.70)	23.35(4.88)	20.66(4.59)	22.45
Distilled water extract of coriander	18.70(3.43)	23.23(4.82)	21.54(4.69)	19.46(4.42)	20.73
Control	34.72(5.93)	27.52(5.22)	25.60(5.11)	24.79(5.02)	28.16
SEm	0.248	0.221	0.021	0.223	
CD (0.01)	1.032	0.922	0.088	0.926	

Figures in parentheses are square root transformed values.

Table 3. Influence of coriander extracts on *T. chilonis*parasitoid recovery pattern of (Free choice test)

Treatments	Number of parasitized eggs/ card (Mean of 20 observation)				Mean
	Exp 1	Exp 2	Exp 3	Exp 4	
Hexane extract of coriander	37.09(6.12)	25.17(5.05)	30.74(5.58)	24.20(4.95)	29.30
Dichloro methane extract of coriander	20.05(4.49)	18.21(4.30)	12.84(3.59)	14.55(3.85)	16.42
Acetone extract of coriander	15.81(4.00)	16.60(4.11)	15.46(3.96)	17.48(4.23)	16.34
Distilled water extract of coriander	18.70(3.43)	14.71(3.86)	21.54(4.69)	9.36(3.13)	16.07
Control	33.24(5.81)	23.20(4.84)	24.43(4.99)	18.73(4.32)	24.90
SEm	0.245	0.272	0.242	0.282	
CD (0.01)	1.057	1.134	1.009	1.173	

Figures in parentheses are square root transformed values.

Table 4. Per cent parasitoid emergence of *T. chilonis* influenced by coriander extracts

Treatments	Number of parasitized eggs/ card (Mean of 20 observation)				Mean
	Exp 1	Exp 2	Exp 3	Exp 4	
Hexane extract of coriander	98.77(0.46)	86.79(3.83)	88.72(3.91)	90.47(2.55)	91.19(1.74)
Dichloro methane extract of coriander	93.26(1.45)	100.00 (0.00)	62.76(7.62)	100.00 (0.00)	89.00(2.26)
Acetone extract of coriander	66.68(7.90)	75.25(5.46)	66.21(7.89)	84.61(3.18)	73.19(6.11)
Distilled water extract of coriander	100.00(0.00)	63.32(8.52)	100.00 (0.00)	82.58 (10.10)	86.48(4.66)
Control	95.74(1.48)	84.30(4.32)	95.43(1.17)	75.55(6.06)	87.76(3.26)

Studies on coriander extracts on parasitization behaviour of *T. chilonis* under laboratory studies:

Studies on extend of parasitization-

With an aim to understand the role of kairomone presence of the intercrop (coriander), the parasitization performance of *T. chilonis* was studied using the laboratory host *Corcyra* egg card treated with kairomones of different solvent system. In the observation I, maximum level of parasitization was noticed in hexane (37.55 eggs/ card) treated *Corcyra* cards and minimum level of parasitization was observed in distilled water (18.70 eggs/ cars) treated *Corcyra* card compared to 34.72 eggs per card in control. In the second observation, the parasitization observed was 18.21 eggs per card in dichloromethane treated *Corcyra* eggs and 29.00 eggs per card in hexane treated *Corcyra* egg card compared to 27.52 eggs per card in control. During observation III, the highest level of parasitization was observed in hexane (34.65 eggs/ card) treated *Corcyra* cards and a low level of parasitization of 20.46 eggs per card was recorded in dichloromethane treated *Corcyra* cards compared to 25.60 eggs per card seen in control. In observation IV, the peak level of parasitization was recorded in hexane (26.75 eggs/ card) extract treated card compared to 24.79 eggs per card in control and a low level of parasitization was recorded in dichloromethane treated *Corcyra* card (14.55) (Table 2).

Based on overall mean, the treatments were in the order of hexane (31.04 eggs/ card) > untreated control (28.16 eggs/ card) > acetone (22.45 eggs/ card) > distilled water (20.73 eggs/ card) > dichloromethane (18.68 eggs/ card).

Studies on parasitoid recovery pattern-

Further observations on the number of parasitoids emerging from the parasitized eggs were made under laboratory condition. For this purpose, the parasitized cards of previous experiment were kept undisturbed in a labelled in zip lock cover and observation on number of parasitoid emerged from each parasitized cards were recorded (Table 3). In overall mean, a maximum parasitoid recovery was recorded in hexane extract treated *Corcyra* card (29.30 eggs) followed by untreated control (24.90 eggs), dichloromethane (16.42 eggs), acetone (16.34 eggs) and distilled water (16.07 eggs).

Studies on parasitoid emergence-

Based on overall mean data, compared to 87.76 per cent parasitoid emergence was seen in control, maximum per cent parasitoid emergence was observed in hexane treated card (91.19 %) followed by dichloromethane treated card (89.00 %), aqueous extract treated card (86.48 %) and 73.19 per cent parasitoid emergence in acetone treated *Corcyra* cards (Table 4).

The result of the present observation is in accordance with the finding of Tandon and

Bakthavatsalam (2005) to reported the volatile compounds obtained from hexane *Tagetes erecta* flower extract to show increased parasitization potential in *T. chilonis.* Yadav *et al.* (2001) reported the presence of pentacosane in potato (*Solanum tuberosum*) and soybean (*Glycine max*) and classified pentacosane as favourable saturated hydrocarbon for *T. exiguum, T. chilonis* was observed to be associated mainly with tricosane, heneicosane, pentacosane and hexacosane during the vegetative period and heneicosane and hexacosane during the flowering period. The coriander extract contains 2-Dodecenal-(E), (E)-Tetradec-2-enal, Octadecane, Nonacosane, Hexadecane, Pentadecane and Heneicosane which are of biologically active fractions on insects.. The findings reveals possible role of such active chemicals in parasitoid compatibility of the intercrop coriander.

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Abundance and diversity of soil arthropods in a tropical deciduous forest and mangrove forest of Kerala, India

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ABSTRACT: The abundance and diversity of soil arthropods in the Marottichal tropical deciduous forest and Kodungallur mangrove habitat of Thrissur District were studied. A total of 98 species belonging to 15 orders and 5 classes were obtained from the study area. Of these, 59 species belonging to 13 orders and 3 classes were recorded from forest habitat and 47 species belonging to 8 orders and 4 classes from mangroves. Order Coleoptera was the most abundant in both forest (30.69%) and mangrove (36.5%) habitats. Sorenson's similarity index showed only 15.09% similarity among species indicating that both the habitats harboured significantly different types of species. It was noted that, as the humidity and moisture decreased, the abundance of species also decreased in both habitats. Temperature was negatively correlated with abundance of species. The diversity in forest habitat (4.03) was higher than mangrove habitat (3.77). Maximum abundance was recorded during monsoon season (June- August) and least during winter season (December- February). The species accumulation curve plotted for the study area indicated that there are more species likely to be discovered in both the habitats. © 2020 Association for Advancement of Entomology

KEYWORDS: Soil arthropods, ecologically different habitats, abiotic factors

INTRODUCTION

Arthropods have long been recognized as important in the functioning of soil ecosystems, and a vast literature accordingly has accumulated, and principal roles played by arthropods in the processes that maintain soil fertility have been reviewed exhaustively (Culliney, 2013). Soils may harbor an enormous number of arthropod species. Arthropods represent as much as 85 % of the soil fauna in species richness. They comprise a large proportion of the meso and macrofauna of the soil. Arthropods function on two of the three broad levels of organization of the soil food web: they are plant litter transformers and ecosystem engineers. The activity and diversity of soil organisms are regulated by a hierarchy of abiotic and biotic factors. The main abiotic factors are climate, including temperature and moisture, soil texture and soil structure, and salinity and pH (Bagyaraj *et al.*, 2016).

In India, only a few studies have been done on soil arthropod diversity in comparison to other groups (Prabhoo, 1971, 1976, 1986). In Kerala more recently Mujeeb *et al.* (2011) studied diversity of soil invertebrates in annual crops, agroforestry and forest ecosystems in the Nilgiri biosphere reserve of Western Ghats and concluded that abundance and diversity of soil invertebrates increased from

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annual crops to forest ecosystem. Bini *et al.* (2016) studied the seasonal variations of soil arthropods in rubber plantations of Central Travancore area and reported that seasonality exerted a strong effect on the abundance and diversity. Lakshmi and Joseph (2016) studied soil micro arthropods in the home gardens in Kerala and found that the occurrence of microarthropods was positively correlated to soil moisture and organic carbon and had negative correlation to soil temperature and soil pH.

The soil arthropods of specific habitats like mangrove forest of Kerala are also poorly understood. The present study on soil arthropods of Marottichal, a tropical deciduous forest and Pullut, a mangrove habitat in Thrissur District will provide baseline data on soil arthropods and their diversity. The study will also help to understand how their diversity varies in different environments and changing abiotic conditions.

MATERIALS AND METHODS

Study area: The study was carried out in two selected habitats of Thrissur District, Kerala. Marottichal forest habitat and Pullut mangrove habitat (Fig. 1). Marottichal forest is part of Western Ghats and is located nearly 22 km from Thrissur Town. The forest is tropical moist deciduous type. The soil is mainly detritus and blackish in nature. The predominant flora includes *Hydnocarpus pentandra, Dalbergia latifolia, Mallotus philippensis, Terminalia paniculata, Embelia ribes, Olea dioica.* The mangrove habitat of Pullut, Kodungalur was encountered in isolated patches. It is located in 10.487 and 76.21ast longitude in Kodungallur taluk, Thrissur. The soil is saline and muddy type. The major flora present include *Avicennia officinalis, Acanthus ilicifolius, Acrostichum aureum*, *Bruguiera cylindrica, Derris uliginosa, Thespesia populnea.*

Soil samples of volume 10×10×10 cm were collected using trowel from 6 different plots randomly for 9 months (June 2017 to February 2018).Time of collection was between 9 AM to 11AM. Separate samples were taken for the estimation of pH, moisture and organic carbon. The collected samples were immediately transferred into polythene bags in order to prevent the loss of moisture. The labelled samples were bought to the laboratory for extraction within 24 hours of their collection. Temperature and humidity were measured using hygro thermometer (HTC-1). Soil pH was recorded using pH meter. The soil moisture was recorded using oven drying method. Organic carbon value of the soil was calculated using Walkley and Black titration method.

Extraction of soil samples was carried out by 'Tullgren Funnel Apparatus' modified by Mac fadyen (1953) with a 40 Watt bulb for providing heat and light and kept for 24 hours. Collected soil samples were preserved in 70% ethanol. The arthropods were first separated into Recognizable taxonomic units (RTU) based on the morphological differences and were later identified up to order level. Each such RTU was given a serial number within that order and the representatives of each RTU were preserved. The specimens were later identified up to order level using standard literature.

Species richness (S) and abundance (N) were calculated and the results were graphically represented. Alpha diversity measures (Dominance index, Shannon index, Evenness, Margalef's richness index) were calculated using PAST. Paired T test (two tailed) was calculated in XLSTAT to determine if the diversity indices along months of tropical deciduous forest and mangroves were significantly different at 5% significance. Sorenson's similarity index was calculated to compare the similarity of species composition in the two study areas.

Different soil parameters like soil pH, relative humidity (%), moisture content (%), temperature (^{o}C) and organic carbon content (%) of each habitat were calculated. Pearson correlation of species abundance with soil parameters was calculated to determine if these factors affected the soil arthropod abundance in the study area.

RESULTS AND DISCUSSION

A total of 402 individuals belonging to 98 species, 15 orders and 5 classes were recorded during the study. Arachnida (3 orders), Diplopoda (1 order),

Fig. 1 Two selected habitats of Thrissur, Kerala - Marottichal forest habitat and Pullut mangrove habitat

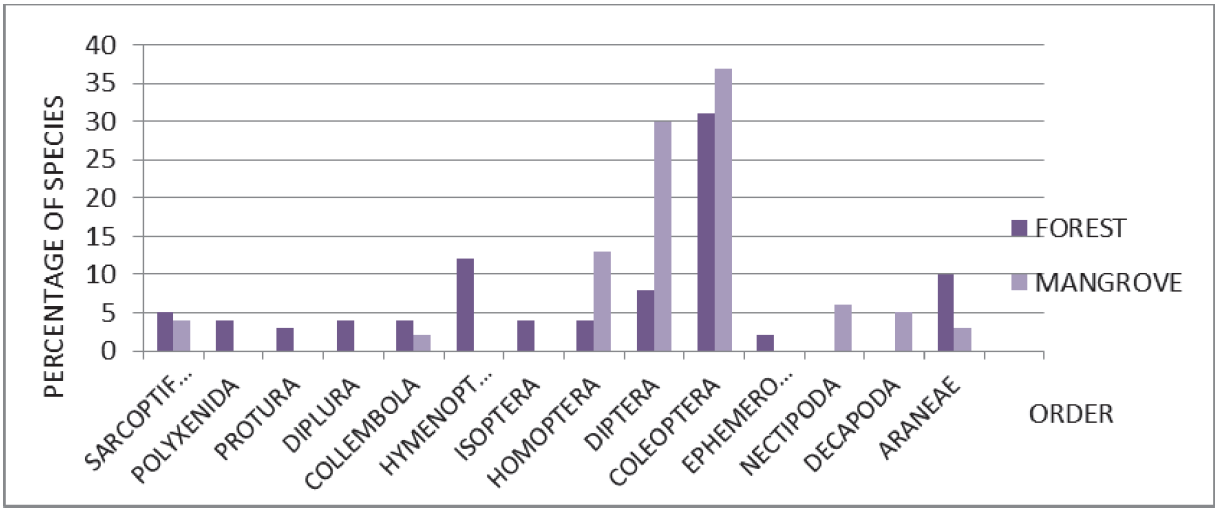

Fig. 2 Distribution of soil arthropods in the habitat

Insecta (9 orders), Remipedia (1 order) and Malacostraca (1order) were the five classes recorded. The 15 orders were Araneae, Pseudoscorpiones, Sarcoptiformes (Class Arachnida), Polyxenida (Class Diplopoda), Protura, Diplura, Collembola, Hymenoptera, Ephemeroptera, Isoptera, Homoptera, Diptera and Coleoptera (Class Insecta), Nectipoda (Class Remipedia) and Decapoda (Class Malacostraca). Of this, 59 species belonging to 13 orders and 3 classes were recorded from forest habitat and 47 species belonging to 8 orders and 4 classes from the mangroves.

In the forest habitat Insecta was the predominant class (71%) followed by class Arachnida (25%) and Diplopoda (4%). Coleoptera was the most abundant insect order (31%) and Ephemeroptera was the least abundant (2%). In the mangrove habitat also class Insecta was most abundant (81%) followed by Arachnida (8%), Remipedia (6%) and

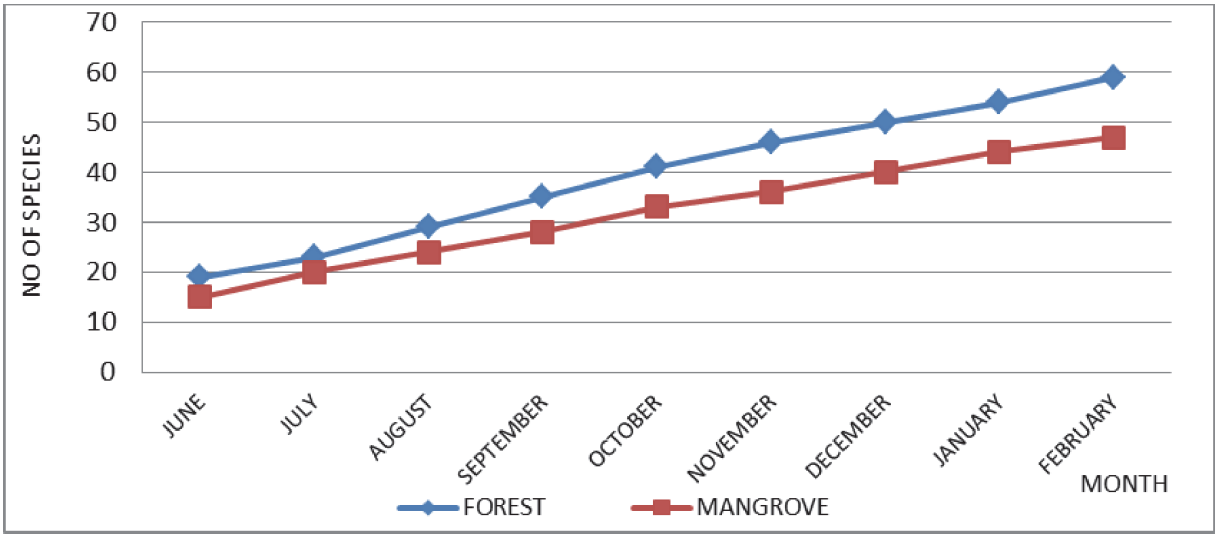

Fig. 3 Species accumulation curve of soil arthropods in different habitats.

Malacostraca (5%). Coleoptera was the dominant order (37%) while Diptera occupied the second position (30%). Order Collembola was least abundant (2%) (Fig. 2). The species accumulation curve did not reached the asymptote indicating that there are more number of species to be discovered in both the habitats (Fig. 3).

Diversity indices of soil arthropods like Shannon index (4.03), Simpson's dominance index (0.98), Margalef's richness (10.93) and evenness (0.95) were higher in the forest habitat (Table 1). Seasonal pattern of diversity indices were calculated. Simpson's index was almost similar during each season in the forest habitat. Maximum diversity was recorded in post monsoon season (3.49) followed by monsoon season (3.47). Evenness (0.94) and Margalef's index (8.17) were higher during post monsoon. However in the mangrove habitat, maximum diversity, dominance and evenness was observed during monsoon season (Table 3). Overall maximum dominance (0.97), Shannon diversity (4.12), evenness (0.92) and Margalef's richness(10.68) was maximum during monsoon season (Table 2). Shannon index and Simpson's index showed significant difference between seasons, the P value being 0.033 and 0.027 respectively (significant at 5% level). Evenness and richness didn't show any significant difference.

Table 1. Diversity parameters of soil arthropods in the study area

	Forest	Mangrove
Taxa_S	59	47
Individuals	202	200
Simpson_1-D	0.98	0.97
Shannon_H	4.03	3.77
Evenness_e^H/S	0.953	0.92
Margalef	10.93	8.68

Sorenson's similarity index between two sites showed 15.09% similarity among species composition indicating that both the habitats harboured significantly different types of species. This might be due to the differences in habitats with respect to environment and micro climatic conditions. Therefore, even though same orders were obtained from both habitats, species were different. Higher species diversity was observed in forest habitat than in mangrove habitat but the abundance was almost similar in both the habitats.

Among the abiotic factors, temperature was negatively correlated with abundance, while humidity and moisture content were positively correlated with abundance. This indicated that soil

Table 2. Seasonal pattern of diversity in the habitat

	Monsoon			Post Monsoon			Winter		
	Forest	Mangrove	Total	Forest	Mangrove	Total	Forest	Mangrove	Total
Taxa_S	35	27	56	34	26	54	30	25	50
Individuals	88	90	178	64	60	124	50	49	99
Simpson_1-D	0.96	0.95	0.97	0.96	0.95	0.96	0.96	0.94	0.96
Shannon_H	3.47	3.18	4.12	3.49	3.09	3.89	3.32	2.87	3.64
Evenness_e^H/S	0.92	0.89	0.92	0.94	0.88	0.90	0.92	0.83	0.87
Margalef	7.59	5.77	10.68	8.17	6.10	10.2	5.66	6.16	8.90

arthropods can flourish only in optimum range of humidity and moisture conditions. Increase in temperature might have caused loss in water content from soil and this might have adversely affected their abundance in both the habitats. Organic carbon content was more in mangrove habitat and showed significant positive correlation with arthropod population (Table 3). pH was positively correlated with arthropod abundance in mangrove habitat, while in forest habitat no significant relation was seen. Lakshmi and Joseph (2016) reported that micro arthropods were positively correlated to soil moisture and organic carbon and negatively correlated to soil temperature and soil pH. Jawaheer (2015) reported significant differences between study sites and months when considering humidity, temperature, soil carbon content and soil moisture. However, no significant difference was recorded between months when considering soil pH and soil calcium.

Table 3. Correlation between soil parameters and arthropod diversity in the study area

Parameters	Forest	Mangrove
Temperature	-0.93	-0.98
Moisture	0.98	0.97
Humidity	0.94	0.97
OC	0.01	0.90
pH	0.38	0.93

The results in the present study can be regarded as a baseline data on the soil arthropod diversity of two ecologically different habitats of Kerala. More intensive studies of longer duration can only substantiate the results obtained in the present study. However, it may be concluded that changes in abiotic conditions can affect the soil arthropod abundance and diversity.

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Influence of colour on oviposition behaviour in green lacewing *Chrysoperla zastrowi sillemi* (Esben - Petersen) (Neuroptera: Chrysopidae)

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ABSTRACT: The Green lacewing, *Chrysoperla zastrowi silleni* (Esben-Peterson), also known as "aphidlion" is a beneficial insect predator of various insect pests. The laboratory experiment was conducted during 2018-19 to evaluate the substrate colour preference for egg laying by *C. zastrowi sillemi*. Egg receiving sheets were pasted with white, black, green, indigo blue, yellow, brown, violet, sky blue, pink, red and orange colour papers. Among all colours *C. z. sillemi* females preferred orange colour as a substrate for egg laying with maximum number of eggs (43.13/female/day) followed by red colour substrate (25.50 eggs/female/day). White and black were least preferred.
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KEY WORDS: C*hrysoperla zastrowi silleni*, colour preference, oviposition

Beneficial insects are important component in the food chain and they afford amenity for maintaining the ecological imbalance in the agro ecosystem. The parasitoids and predators devour the agricultural insect pests at egg, larval/ nymphal, pupal and adult stages and bring down the pest load below economic threshold level (Ballal and Verghese, 2015). The entomophagous insects have the ability of reducing the pest population below 30% under field condition even without insecticide application. The green lacewings are efficient and successful predators in the management of insect pests (Karthika *et al.,* 2015). The use of green lacewing, *Chrysoperla zastrowi sillemi* (Esben - Petersen) (Neuroptera : Chrysopidae) has gained importance in pest management in India (Elango and Sridharan, 2017). It has long been considered as an important natural predator because of its potential to control a variety of soft bodied insects like aphids, whiteflies, coccids, mealybugs and thrips (Rao and Satyanarayana, 1984; Henry *et al*., 2010).

Mass culturing of *Chrysoperla zastrowi sillem*i

Grubs were reared in GI round basins (28 cm dia) at 250 larvae/ basin covered with khada cloth. The eggs of *Corcyra cephalonica* were given as feeding material for the larvae in the laboratory. The *C. z. sillemi* larvae pupate into round white coloured silken cocoons in ten days. The cocoons were collected with fine brush and transferred into 1 litre plastic containers with wire mesh window for emergence of adults. The adults are collected

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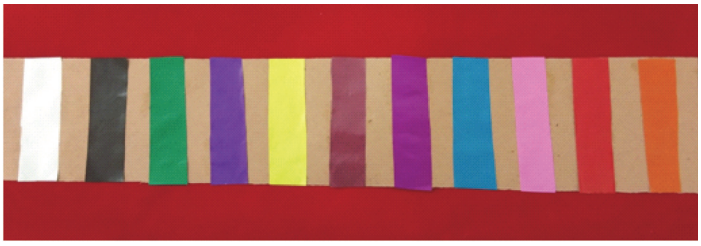
Table 1. Substrate colour preference for egg laying of *C. zastrowi sillemi*

S.No	Treatments	No.of.eggs laid by *C. zastrowi sillemi**								Total	Mean
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8		
1	White	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	2.00 (1.41)	0.00 (0.00)	0.00 (0.00)	2.0	0.25
2	Black	1.00 (1.00)	1.00 (1.00)	17.00 (4.12)	3.00 (1.73)	1.00 (1.00)	23.00 (4.80)	5.00 (2.24)	3.00 (1.73)	54.0	6.75
3	Green	9.00 (3.00)	8.00 (2.83)	14.00 (3.74)	10.00 (3.16)	8.00 (2.83)	16.00 (4.00)	2.00 (1.41)	37.00 (6.08)	104.0	13.00
4	Indigo blue	1.00 (1.00)	0.00 (0.00)	21.00 (4.58)	2.00 (1.41)	22.00 (4.69)	14.00 (3.74)	4.00 (2.00)	0.00 (0.00)	64.0	8.00
5	Yellow	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.00 (2.24)	4.00 (2.00)	0.00 (0.00)	0.00 (0.00)	2.00 (1.41)	11.0	1.38
6	Brown	1.00 (1.00)	1.00 (1.00)	0.00 (0.00)	0.00 (0.00)	2.00 (1.41)	8.00 (2.83)	0.00 (0.00)	0.00 (0.00)	12.0	1.50
7	Violet	0.00 (0.00)	9.00 (3.00)	2.00 (1.41)	4.00 (2.00)	5.00 (2.24)	10.00 (3.16)	0.00 (0.00)	0.00 (0.00)	30.0	3.75
8	Sky blue	7.00 (2.65)	11.00 (3.32)	26.00 (5.10)	10.00 (3.16)	16.00 (4.00)	42.00 (6.48)	4.00 (2.00)	16.00 (4.00)	132.0	16.50
9	Pink	25.00 (5.00)	19.00 (4.36)	6.00 (2.45)	2.00 (1.41)	14.00 (3.74)	31.00 (5.57)	3.00 (1.73)	4.00 (2.00)	104.0	13.00
10	Red	29.00 (5.39)	21.00 (4.58)	10.00 (3.16)	17.00 (4.12)	41.00 (6.40)	17.00 (4.12)	25.00 (5.00)	44.00 (6.63)	204.0	25.50
11	Orange	41.00 (6.40)	11.00 (3.32)	59.00 (7.68)	26.00 (5.10)	17.00 (4.12)	69.00 (8.31)	36.00 (6.00)	86.00 (9.27)	345.0	43.13
	Total	114.00	81.00	155.00	79.00	130.00	232.00	79.00	192.00	1062.00	132.75
	SEd	0.0759	0.0500	0.0606	0.0478	0.0595	0.0767	0.0331	0.0842	-	-
	CD (P = 0.05)	0.1582	0.1043	0.1263	0.0996	0.1241	0.1599	0.0691	0.1756	-	-

* Mean of eight replications, standard error values are given in parantheses.

a. Mass culturing of *Chrysoperla zastrowi sillemi*

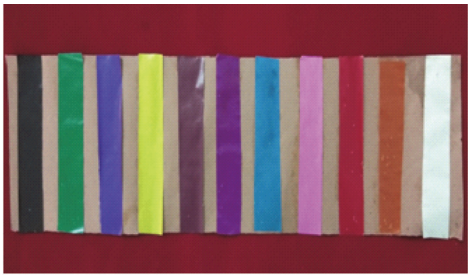
b. Brown sheet with various substrate colours used in the experiment



c. G.I. round troughs with colour sheets

d. Releasing of adults

e. Maximum egg laying of *C. zastrowi sillemi* on Orange and Red sheets



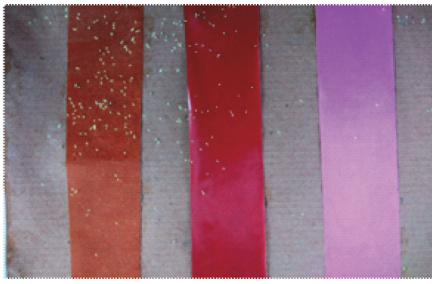


Fig 1. Substrate colour preference for egg laying of *C. zastrowisillemi*

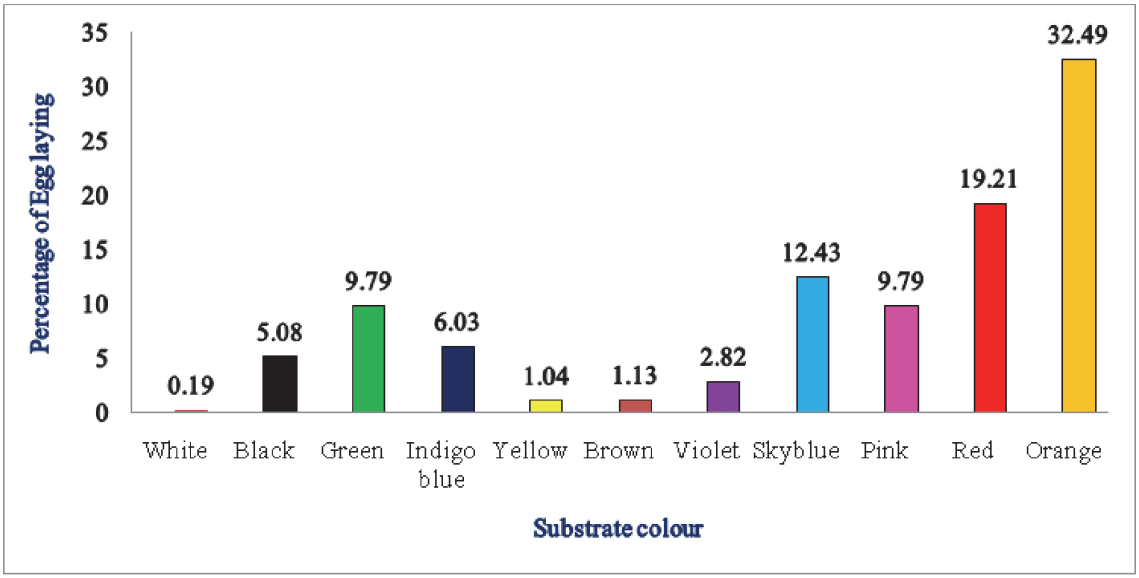


Fig 2. Percentage of egg laying of *C. zastrowi sillemi* on different colour substrates

daily and transferred to pneumatic glass troughs or GI round troughs (30 cm x 12 cm). Before allowing the adults, the rearing troughs were wrapped inside with brown sheet which act as egg receiving card. About 250 adults (60% females) were allowed into each trough and covered with white nylon or georgette cloth secured by rubber band. Three bits of foam sponge (2 sq.in) dripped in water were kept above the nylon cloth cover. Besides an artificial protein rich diet (yeast, fructose, honey, Proteinex ^{R} and water in the ratio 1:1:1:1) was provided in semisolid paste form in three spots on the cloth outside. The adults were collected daily and allowed into fresh rearing troughs with fresh food. From the old troughs, the brown paper sheets along with *Chrysopa* eggs were removed and used for maintaining culture of chrysopids.

Substrate colour preference for egg laying of *C. zastrowi sillemi*

An experiment was conducted during 2018-19 in the biocontrol laboratory, Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore to evaluate the substrate colour preference for egg laying by *C. z. sillemi*. The rearing troughs are wrapped inside with brown sheet which act as egg receiving card. Sheets were pasted with white, black, green, indigo blue, yellow, brown, violet, sky blue, pink, red and orange colour papers (Table 1). Twenty pairs of male and female were confined in GI round troughs (30 cm x 12 cm) to lay eggs for 20 days. The eggs laid on the coloured papers were collected and counted carefully. This experiment was replicated eight times.

The data were analyzed using analysis of variance (ANOVA) using AGRES 3.01 and AGDATA software. Data in the form of percentages were transformed to arcsine values and those in numbers were transformed to $\sqrt{(x+0.5)}$ and analyzed. The mean values of the treatments were compared using DMRT at 5 per cent level of significance. During the process, the insects attracted to the non colour sheets to test the difference in insect count between the coloured and ordinary sheets, t test was carried out. Before t test, the unknown variance of the two groups is tested using F test.

Females of C.*z.sillemi* visually distinguished different colours and preferred certain colours as a substrate for egg laying. The egg laying was started by *C. z. sillemi* after 6 days of release inside cage. The egg laying was continued up to eight days. Among the various colours of substrate, *C.z.sillemi* females preferred orange colour as a substrate for egg laying and laid the maximum

number of eggs (43.13/ female/day) followed by red colour substrate (25.50 eggs/ female/day). Skyblue colour had 16.50 eggs/ female/day. Brown and yellow colour substrates were statistically on par with each other. White colour was least preferred by *C. z. sillemi* for egg laying.

Different colour charts are used to test the insect attraction the number of insects are counted. The critical value $F_{(0.05,87)}$ is 1.43 which is less than the calculated value (2.44). The two groups are having significantly different variances. Since, two groups have different variances; t test for unequal variance was used to calculate the significant difference between two groups (coloured and ordinary). Thecritical value $t_{(0.05,148)}$ is 1.66 which is less than the calculated value (1.66). So, the two means are significantly different from each other.

After that, the significant difference among the different colour bands for the two groups were identified separately using the ANOVA for coloured groups calculated value F(0.05,10,77) is 13.811 and probability lesser than 0.05. Insects attracted to the different colour bands are significantly different. The Critical difference at 5% level of significance between the colour bands are estimated as 1.316. This analysis infer that, T11 and T10 bands attract more insects than the other bands. Since, our target is the better colour band; the ordinary may not be useful. If needed, it can be interpreted as above stanza.

Green lacewing fly, *C. z. sillemi* females preferred orange colour as a substrate for egg laying and laid the maximum number of eggs (43.13) followed by red colour substrate (25.50 eggs). So far there are no such studies on *C.z.sillemi* egg laying colour preference. However, Sattar and Abro (2011) reported least preference to green and brown colour by *C. carnea* females for egg laying. Carvalho *et al*. (2002) have determined the influence of density of green lacewing, *C. mediterranea* adults on their production potentialAnonymous (1994) also reported black as most preferred colour for oviposition in *C. carnea.*

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Evaluation of acaricides against false spider mite, *Tenuipalpus aboharensis* (Acari: Tenuipalpidae), a pest of pomegranate

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ABSTRACT: False spider mites are serious pests of pomegranate and frequently cause considerable economic losses in other fruit crops as well. A field experiment conducted to evaluate eleven acaricides against *Tenuipalpus aboharensis* infesting pomegranate plants, revealed that wettable sulphur at 2.5 g and dicofol at 2.5 ml per litre were very effective and other acaricides *viz.* propargite, fenpyroximate, chlorfenapyr and buprofezin were also found effective against *T. aboharensis*.
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KEY WORDS: *Tenuipalpus aboharensis*, chemical control

Pomegranate (*Punica granatum* L.), a member of botanical family Punicaceae is native to central Asia, but since it is highly adaptive to a wide range of climates and soil conditions, it is grown in many different geographical regions including the Mediterranean basin, Asia, and California (Holland *et al*., 2009). It is considered one of the most important fruit crops of the tropical and subtropical region because of low maintenance cost, good yields, keeping quality and ability to thrive with limited moisture (Anonymous, 2005). India produces five lakh tonnes but exports only 5000 tonnes, whereas Spain produces one lakh tonnes and exports 75,000 tonnes and its export ends by December. India has the vast scope to export to European countries from January to June. Pomegranate cultivation is one of the most remunerative farming enterprises in India. It is grown in Maharashtra, Karnataka, Andhra Pradesh and Gujarat on a larger scale, its coverage is about 38,500 ha, whereas in Karnataka its total area is 5,289 ha with an annual production of 30,676 tonnes (Jagadish *et al.*, 1998). It is cultivated mainly in the districts of Tumakuru, Kolar, Bangalore, Mysore, Chitradurga, Dharwad, Vijayapura and Belagavi.

Of several pests which affect the successful production of pomegranate, at least five species of mites are also known to infest the pomegranate plant, these are *Tenuipalpus punicae* Pritchard and Baker, *Tenuipalpus aboharensis* Sadana and Chabra, *Brevipalpus phoenicis* Geijeskes, *Aceria granati* (Canestrini and Massalongi) and *Oligonychus punicae* (Hirst) (Sadana, 1997; Al-Jboory and Al-Swuidy, 2006). The mites infest the younger leaves mainly. Infestation of the tenuipalpid

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mites (*T. punicae, T. aboharensis* and *B. phoenicis*) causes the leaves to turn yellowish and dry; mites are found on the entire lamina, whereas, infestation by the eriophyid (*A. granati*) results in the edges of the leaves to roll. This makes the leaf lamina to become narrower and affects the overall growth of the plant. Occasionally leaf edge rolling is associated with thrips infestation also. Since pomegranate is considered a high-value crop, farmers invest heavily and as a result damage by the pests needs to be addressed. In Karnataka, *T. aboharensis* has been observed as a serious pest of pomegranate during summer period especially in places surrounding Pavagada in Tumakur district and Hiriyur in Chitradurga district. Though no information or data is available on the extent of damage caused due to severe mite infestation, in such situations growers are resorting to application of broad spectrum insecticides. Hence the current study was conducted to determine the effectiveness of available acaricides against this mite.

A field experiment was carried out to evaluate 11 acaricides against *T. aboharensis* on pomegranate (cv. Bhagwa) at Pavagada village, Tumakuru district, 200 km from Bangalore. The experiment was laid out in Randomized Complete Block Design (RBD) with 12 treatments including untreated (water-spray) control in 3 replications (Table 1). The plants were three and half years old, row spacing was 15 feet and plant to plant spacing was 15 feet. Size of the experimental area was 50 m x 50 m with 180 plants. Five plants in a row were considered as a plot for imposing the acaricide treatment. A high volume knapsack sprayer was used for spraying, taking care to cover entire plant including both upper and lower surfaces of leaves. The first spray was carried out during last week of February and the second spray during the first week of May 2008, when the crop had high mite infestation. For recording the observations, from each plant sample of three leaves, one each from the top, middle and bottom canopy were collected and brought to the laboratory in polyethylene bags. The number of eggs and active stages (larvae, nymphs and adults) of *T. aboharensis* on both the surfaces of each of the leaf was recorded under a stereo binocular microscope. *T. aboharensis* population was computed as the mean number of all stages (eggs + active stages) per leaf. The

Table 1. Treatment details of field experiments at Pavagada during Feb. to May 2008

Treatment	Chemical	Dose	Source
T_1	Wettable sulphur	2.5 g/l	Share 40SC
T_2	Dicofol	2.5 ml/l	Colonel 18.5EC
T_3	Abamectin	0.4 ml/l	Abacin 1.9EC
T_4	Fenazaquin	1.7 ml/l	Magister 10EC
T_5	Propargite	1.3 ml/l	Omite 57EC
T_6	Fenpyroximate	0.8 ml/l	Neon 5EC
T_7	Diafenthiuron	1.2 g/l	Pegasus 50WP
T_8	Buprofezin	0.8 ml/l	Applaud 25EC
T_9	Mineral oil	5 ml/l	-
T_{10}	Fish oil Rosin soap	5 g/l	-
T_{11}	Chlorfenapyr	1 ml/l	Intrepid 10EC
T_{12}	Control	Water spray	-

Table 2. Bioefficacy of selected acaricides against *Tenuipalpus aboharensis* on pomegranate

Acaricides	Mean number of mites (eggs + active stages)/leaf				
	First spray				
	Pre- treatment	7 DAS	14 DAS	21 DAS	28 DAS
Wettable sulphur	47.33 (6.85)	20 (4.43)^{a}	10.80 (3.35)^{a}	16.46 (4.09)^{a}	31.93 (5.56)^{a}
Dicofol	86 (9.25)	22 (4.70)^{a}	12.66 (3.61)^{a}	16.86 (4.11)^{a}	29.33 (5.39)^{a}
Abamectin	91 (9.51)	36.93 (5.98)^{a}	19.60 (4.46)^{a}	25.60 (5)^{a}	32.66 (5.04)^{a}
Fenazaquin	111.4 (10.09)	69.53 (7.65)^{ab}	52.13 (6.15)^{ab}	53 (7.06)^{ab}	54.93 (7.11)^{a}
Propargite	35 (6.03)	24.93 (4.96)^{a}	17.86 (4.27)^{a}	27.40 (5.24)^{a}	41.26 (6.39)^{a}
Fenpyroximate	71.80 (7.15)	24.46 (4.86)^{a}	13.06 (3.62)^{a}	21 (4.58)^{a}	29.40 (5.41)^{a}
Diafenthiuron	51.80 (7.15)	26.86 (5.20)^{a}	19.06 (4.37)^{a}	26.66 (5.20)^{a}	43.06 (6.07)^{a}
Buprofezin	74 (8.51)	34.60 (5.76)^{a}	25.86 (4.67)^{a}	42.53 (6.05)^{a}	48.33 (6.21)^{a}
Mineral oil	56.26 (7.52)	31.26 (5.61)^{a}	19.06 (4.48)^{a}	18.06 (4.28)^{a}	33.33 (5.80)^{a}
Fish oil Rosin soap	267.20 (14.45)	189.46 (12.37)^{c}	113.06 (9.74)^{bc}	116.53(10.23)^{bc}	136.66(11.19)^{b}
Chlorfenapyr	80.66 (8.88)	33.40 (5.71)^{a}	26.66 (5.04)^{a}	46.06 (6.60)^{a}	54 (7.16)^{a}
Control	116.66 (10.78)	143.33 (11.93)^{bc}	156.66 (12.49)^{c}	166.66 (12.89)^{c}	173.33 (13.18)^{b}
F test	NS	*	*	*	*
SEM±	(1.86)	(1.57)	(1.28)	(1.11)	(1.25)
CD at P=0.05	-	(4.6)	(3.78)	(3.25)	(3.67)

*DAS: Days After Spray; Figures in parentheses are √(x+0.5) transformed values; NS: Non-significant; *:Significant; Treatments with same alphabetical superscript within the column are statistically on par.*

pretreatment observations were recorded one day before spray and post-treatment observations were recorded on 7th, 14th, 21st and 28th day after spray. In case of second spray, the population was recorded on 7th and 14th day after spray. The mite population data from the field experiment were subjected to √(x+0.5) transformations and analyzed statistically for comparing treatment following Analysis of Variance technique (ANOVA) and the results were interpreted at 5% level of significance.

The present study revealed that all acaricides tested were effective in controlling *T. aboharensis* (Table 2 and 3). General abundance of *T. aboharensis* in the experimental plots was uniform before the imposition of different treatments. Seven days after first spray, wettable sulphur gave the best control followed by dicofol, fenpyroximate, propargite, diafenthiuron, chlorfenapyr, mineral oil, buprofezin and abamectin; however all these were statistically on par, while fenazaquin was not statistically significant from control. Fish oil rosin soap was least effective since the mite population was high. Fourteen days after first spray, the order of effective chemicals was same as those on seven days after spray, only abamectin was better than chlorfenapyr. Twenty-one days after first spray the order of effectiveness was almost similar except that chlorfenapyr was better than fenpyroximate and effectiveness of abamectin was also found improved. Twenty-eight days after first spray abamectin was best whereas wettable sulphur was less effective than dicofol, followed by fenpyroximate, chlorfenapyr, diafenthiuron,

Table 3. Bioefficacy of selected acaricides against *Tenuipalpus aboharensis* (eggs +active stages) on Pomegranate

Acaricides	Mean number of mites (eggs + active stages)/leaf		
	Second spray		
	Pre-treatment	7 DAS	14 DAS
Wettable sulphur	223.46 (14.71)	94.86 (9.68)^{abc}	139.80 (11.71)^{b}
Dicofol	142.26 (11.92)	50.66 (7.06)^{ab}	56.66 (7.53)^{a}
Abamectin	493.73 (21.91)	146.80 (12.04)^{cd}	135.80 (11.61)^{b}
Fenazaquin	171.66 (12.86)	39.53 (6.28)^{a}	67.20 (8.19)^{ab}
Propargite	123.20 (10.73)	50.13 (7.01)^{ab}	48.93 (6.83)^{a}
Fenpyroximate	225.76 (14.89)	103.33 (9.68)^{abc}	80.53 (8.87)^{ab}
Diafenthiuron	382.80 (19.47)	140.60 (11.73)^{bcd}	105.93 (10.17)^{ab}
Buprofezin	171.00 (13.09)	64.60 (7.89)^{abc}	102.46 (10.13)^{ab}
Mineral oil	159.80 (12.64)	73.26 (8.56)^{abc}	80 (8.88)^{ab}
Fish oil Rosin soap	374.53 (18.98)	276.13 (15.71)^{d}	380.20 (19.11)^{c}
Chlorfenapyr	144.06 (11.99)	65.73 (8.02)^{abc}	109.46 (10.46)^{ab}
Control	201.20 (13.80)	241.73 (15.16)^{d}	350 (18.41)^{c}
F test	NS	*	*
SEM±	(1.75)	(1.69)	(1.27)
CD at P=0.05	-	(4.97)	(3.74)

DAS: Days After Spraying; Figures in parentheses are $\sqrt{x}+0.5$ transformed values
*NS: Non-significant ; * Significant*
Treatments with same alphabetical superscript within column are statistically on par

buprofezin, propargite, fenazaquin, mineral oil and were statistically on par. Fish oil rosin soap was observed to be next in the effectiveness; the total number of mites (active stages & eggs) in untreated control was 173.33/leaf (Table 2).

Seven days after second spray fenazaquin and propargite were better, followed by buprofezin, dicofol, chlorfenapyr, mineral oil, fenpyroximate, wettable sulphur; all these were statistically on par, while diafenthiuron and abamectin were not significantly different from control. Fish oil rosin soap was less effective since the mite population was high. Fourteen days after second spray propargite was best, whereas buprofezin was less effective than dicofol followed by fenazaquin, fenpyroximate, chlorfenapyr, mineral oil and diafenthiuron; were statistically on par. Wettable sulphur and abamectin were observed to be next in the order of efficacy. Fish oil rosin soap was again found less effective. The total number of eggs and active stages recorded in untreated control was 551.66 mites/leaf (Table 3).

Among the different acaricides tested, wettable sulphur was found effective on both eggs and active stages up to 21 days after application following the first spray. Dicofol (2.5 ml/litre) was observed as the next best acaricide after wettable sulphur, especially on the active stages after both the sprays. Propargite was found effective on eggs, 7 days after spraying in both sprays. However, all the chemical acaricides were found effective on *T. aboharensis* since the mite population on sprayed plants was

significantly lower than on unsprayed plants. Literature on management of *T aboharensis* is not available and hence the results of management trials on *Brevipalpus phoenicis* which is also a tenuipalpid mite is considered here. Raga *et al.* (1990) tested fenpropathrin, propargite, dicofol, hexythiazox and bromopropylate and found that all were effective against the mite, similar to the results obtained in the present study.

Holland *et al* (2009) found that abamectin, fenpyroximate, spirodiclofen and etoxazole were effective against *B. phoenicis* in Egypt. Sudoi (1990) observed that dicofol was effective on *B. phoenicis* in Kenya. Gowda *et al*. (2007) found that wettable sulphur, dicofol and profenophos were effective against arecanut red mite *Raoiella indica* Hirst, which agrees with the present findings with regard to the effectiveness of wettable sulphur and dicofol.

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